HEIDELBERG UNIVERSITY

MASTER THESIS

Thesis Title

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"Whatever source of water they can find is what they have."

Interviewee 3

Chapter 1

Introduction

Water is a crucial element for sustaining life, and access to it is a fundamental necessity for every society and human being. Nonetheless, water security is increasingly becoming a pressing issue affecting the lives of billions of people across the world (Caretta et al. 2022). In order to meet this challenge, the United Nations have already recognized the importance of water security in 2015 and have made clean water and sanitation the sixth Sustainable Development Goal (UN 2016). Yet, in many regions water scarcity as a long-term water supply/demand imbalance is expected to further deteriorate leading to the recent announcement of the World Meteorological Organization that *"water scarcity [...] is one of the greatest challenges of the twenty-first century"* (IDMP 2022, p. 7).
Droughts, known for their widespread and potentially extreme impacts, can further exacerbate a strained water scarcity situation (IDMP 2022). With the projection of rising frequency and intensity of droughts throughout vast parts of the African continent, measures for prediction, monitoring and evidence based anticipatory actions and management become ever more important (**adelekanAfricaClimateChange2022**; Abdulkadir 2017; Nationen 2021).
As Somaliland is characterised by a semi-arid four-season climate with two extended dry seasons and an economic backbone of pastoralism and rain-fed agriculture, access to water is crucial. (Abdulkadir 2017; Petrucci 2022; Somaliland 2021). Furthermore, Somaliland is no exception to the above mentioned climatic trend and with more than 17 major droughts in the last 60 years, a recent famine in 2010-2012, and an increasingly devastating situation again since 2018, Somalia is severely affected by droughts (Abdulkadir 2017; CRED 2023). The final report of the FbF feasibility study identified five other hazards besides drought, namely floods, cyclones, diseases, locusts and conflict. But of all these hazards, drought was ranked as the greatest threat due to its increasing frequency, severity and far-reaching consequences (SCRS 2022).
The Forecast based Financing (FbF) programme was started in 2007 by the Red Cross Red Crescent Movement together with the Red Cross Red Crescent Climate Center to facilitate Anticipatory Actions instead of post-disaster reactions (IFRC and GRC 2019). Together with their local partners, the International Federation of Red Cross and Red Crescent Societies (IFRC) is working on establishing so called Early Action Protocols (EAPs) to ensure better organization and coordination of AAs in the face of an incoming disaster.

These Anticipatory Actions are based on a predefined interplay of evidence based forecasts, triggers, actions and financing mechanisms to ensure rapid reactions.
Triggering AAs is generally linked to certain forecast thresholds. Once these thresholds are reached, the AAs are carried out. Forecasts are most often based on existing drought indicators and indices such as EDDI, SPI, SPEI mostly integrate physical indicators and refer primarily to the macro and international level and are thus relatively coarse (Svoboda, Fuchs, and (IDMP 2016). Fine grained up-to-date forecasts which not only include physical but also social circumstances and knowledge on local levels are rare or even non-existent (Enenkel et al. 2020; Masinde and Bagula 2010). "However, assessments focused only on physical variables and processes fail to capture why drought matters [...]."(Lackstrom, Farris, and Ward 2022, p. 3) and how it directly impacts communities (Boult et al. 2022; Enenkel et al. 2020).
Besides the further development of more fine grained technical solutions, the integration of local citizens is another way forward. Engaging local citizens and communities and giving them an active voice in defining and co-producing AAs and knowledge can be of multiple benefit to a wide variety of aspects and enrich the data generated (SCRS 2022; Njambi-Szlapka and Jones 2022). Scientific processes of e.g. linking climate variability to local water security can be informed, the public's education and awareness about specific topics can be raised, and decision-making and overall management can be enhanced by local knowledge, if the project is embedded in these procedures (Huang et al. 2020; Kirschke et al. 2022; E. Minkman 2015). The IFRC states, that the "community engagement and accountability (CEA) is essential [] to build acceptance and trust for effective and sustainable outcomes (IFRC 2022).
In the last two decades, Citizen Science has become a vibrant area of scientific interest covering various aspects in many different contexts (Kirschke et al. 2022; Kullenberg and Kasperowski 2016). Relatively recent developments in Community-based monitoring and Mobile Crowdsensing now make it possible for a large number of citizens to contribute to scientific, social and environmental endeavours with just a simple phone (Butte et al. 2022). By applying these approaches, CS projects have demonstrated their ability to gather and fill data gaps particularly in formerly data sparse regions in an effective and cost-efficient manner (Butte et al. 2022; Lackstrom, Farris, and Ward 2022; Weeser et al. 2018). However, currently CS projects and studies are primarily located in North America, Europe and Australia (Kirschke et al. 2022; Koehler and Koontz 2008; Canada, T. G. Foundation, and WWF-Canada 2018). Social.Water, CoCoRaHS and (Speir et al. 2022)'s study are examples of those environmental data collection and drought monitoring implementations focussing on monitoring river, lake, groundwater and precipitation levels. Yet, all these approaches require internet access and more technical equipment, making them unfeasible for low-income conditions (Fienen and Lowry 2012; Lackstrom, Farris, and Ward 2022; Lowry et al. 2019).
Most developed frameworks and guidelines therefore primarily represent experiences and applications from above mentioned regions and thematic foci. However, broadly comparable projects show the general applicability of participatory monitoring approaches

also in the Global South (BRCiS, OCHA, CBS, weeser 2018). In particular, the Community-based Surveillance project established by the SRCS and others to survey diseases in order to prevent outbreaks through Anticipatory Actions in Somaliland, show the local implementability (IFRC 2017; SCRS 2022).

The presently very challenging water resource situation in Somaliland requires comprehensive, effective and efficient solutions. The current Early Action Protocol developments under the umbrella of FbF could be a potential candidate, but preventive activities are currently severely limited by the poor data situation. Therefore, the local National Society, the Somalia Red Crescent Society (SRCS) calls for new and innovative approaches to close this information and management gap. Building on the methods developed and experience gained from thematically comparable projects and local implementations, this work attempts to reduce this gap by *adapting and applying an approach for community-based participatory mapping and monitoring of water sources in a water-scarce and resource-limited setting in collaboration with a national non-governmental organization to facilitate respective Anticipatory Actions in the context of Forecast based Financing, with the goal of improving water management and availability to address water shortages*. In order to provide a basis for the practical implementation of this goal, two research questions need to be addressed and answered:

RQ1. How can a replicable and adaptable framework for community-based participatory water source mapping and monitoring in regard to the research aim and the overall case study context be developed?

RQ2. In the specific context of this case study, how can the developed framework be applied to create a tailored roadmap for the implementation of a community-based participatory water source mapping and monitoring project for triggering Anticipatory Actions to address water shortages in Somaliland?

For the purpose of answering these research questions, this thesis is structured as follows: Chapter 2 introduces fundamental concepts and provides relevant background information on the case study area. Chapter **??** covers the methodology for developing and applying the framework and Chapter 4 presents the resulting findings. These two chapters start with the methodological framework development in the first part and continue with the application-oriented topic in the second part. The subsequent discussion of the methods, results and limitations in Chapter 5 is structured in the same way, also with regard to the sequence of important topics. The conclusion in Chapter **??** summarises the main findings, reflects on the questions and results in terms of their contribution to science and practice and provides an outlook for further work.

Chapter 2

Theoretical Background

2.1 Introduction

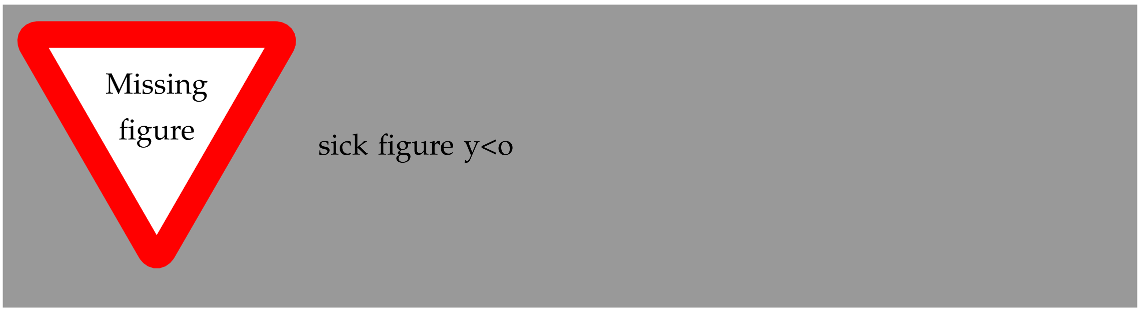
This chapter provides an introduction to the main concepts, theories and literature in which this thesis is embedded. Context is given by presenting current definitions together with their characteristics and differences of broad concepts such as water security, water scarcity and drought. Building on this foundation, the approach to measure and monitor these wide concepts via indicators and indices together with the ideas of risk, vulnerability and impact is introduced. Extending the previously prevailing idea of the Disaster Risk Reduction (DRR) cycle of mitigation, preparation, response and recovery, the rather recently emerged concept and operationalisation of Forecast based Financing (FbF) is described in detail. The details cover aspects of structure, decision-making based on forecasts, setting strict thresholds for when to act, and finally what to do when thresholds are reached. Building on the realisation that the current data basis for predictions is too coarse for precise measures, another broad field is introduced, that of Citizen Science (CS). After CS is introduced, it is further extended to areas of interest specifically focussing on community collaboration, data acquisition and the integration of information technology infrastructure. Community-based Surveillance (CBS) and Community-based Water Monitoring (CBWM) are given as concise examples for successful implementation in local context and thematic transferability of the approach, respectively. Before coming to a summary of the literature, the case study is described. Geographical and climatic conditions as well as historical and current economic and socio-cultural contexts are discussed. Furthermore, the wide-ranging concepts from the beginning will be embedded in local contexts and previous efforts and activities to implement anticipatory measures will be described. The chapter is concluded by a summary.

2.2 Fundamental concepts - Water Security, Water Scarcity and Drought

Water security is a theoretical construct that has emerged in the 21st century to frame the overall water objectives and goals to guide local to global water management and policy development (**sadoffWaterSecurity2020a**). It "links together the web of food, energy, climate, economic growth, and human security challenges that the world economy faces over the next two decades" (WEF 2009, p. 5). In more detail, it is about "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies."(D. Grey and Sadoff 2007). Water security integrates therefore economic, social and environmental dimensions into an interconnected and complex network of human and natural relations by addressing risks of too much, too little or poor quality water (Van Beek and Arriens 2014; Mishra et al. 2021). Due to the focus of this work, emphasis is placed on factors that decrease water security due to too little water availability. Besides other factors, natural disasters such as droughts, and water scarcity are the main drivers for insufficient quantities of water (Caretta et al. 2022). Water quality and access are briefly addressed in addition to provide a more comprehensive understanding of water security for the following chapters.

2.2.1 About Drought

Drought as highly complex and severe climate-related multi-hazard has far reaching, cascading and interconnected consequences affecting natural ecosystems, societies and economies (see figure **??**)(Nationen 2021). Historically, droughts are a recurring feature that can occur in all climates. They can geographically extend over small areas to entire sub-continents and are slow onset events that can persist for a few weeks to several years. These high spatial and temporal variabilities make drought not only challenging to define but due to its slow onset, droughts are often only recognized when they are well advanced (IDMP 2022; Nationen 2021). While some drought conditions over large areas can be associated to some low-frequency changes in atmospheric conditions such as the El Niño, accurate cause identification can be rather challenging on smaller scales and requires many different parameters (Botai et al. 2019; Nationen 2021).



This complex conglomeration of interrelated causes and effects of multiple temporal, spatial and thematic dimensions makes the definition of *drought* a fairly multi-layered undertaking (Balint et al. 2013). Several well-known definitions are, for example, from the (English language 2022) defining drought as "a long period of abnormally low rainfall, especially one that adversely affects growing or living conditions". (Palmer 1965, p. 2) defines drought as "a prolonged and abnormal moisture deficiency." or (Van Loon et al. 2016) defines droughts simply as "an exceptional lack of water compared to normal conditions". Other drought definitions emphasize its natural and/or human origin, its special characteristics, impact and temporal duration or even understand "drought as a system of causality where the link between causes and effects is random in nature (Balint et al. 2013; Balti et al. 2020; IDMP 2022; Loon et al. 2016; W. Wang et al. 2016; Wilhite and Glantz 1985). Already in the 1980s, (Wilhite and Glantz 1985) found more than 150 published definitions of drought. Besides the categorization into a conceptual or operational category , (Wilhite and Glantz 1985) proposed a clustering of these definitions into four types, namely meteorological drought, agricultural drought, hydrological drought and socio-economic drought. This classification is still widespread today (Balint et al. 2013; Balti et al. 2020; IDMP 2022; Nationen 2021).

The conceptual category refers to a general formulation of an idea of drought to understand its concept and identify its boundaries and is often formulated in relative terms (Wilhite and Glantz 1985). Definitions in the operational category try to define how drought functions in terms of its onset, duration, severity and spatial coverage also covering how this can be measured via indices (**nationaldroughtmitigationcenterWhatDrought**; Balint et al. 2013; Wilhite and Glantz 1985). With these definitions, the current situation is usually compared to a historical average, which is usually based on a 30-year period, presupposing the development and continuous measurement of indicators and indices that can be used. (Nationen 2021; Wilhite and Glantz 1985).

The four types of drought are commonly conceptually defined and brought into practice by operational specifications. They can be understood as different, but complementary stages of the same process and are generally cascading in reason and time but can overlap and are difficult to completely unravel. Table displays the four types at a glance and figure shows an overview about the different types, their succession and cascading elements.

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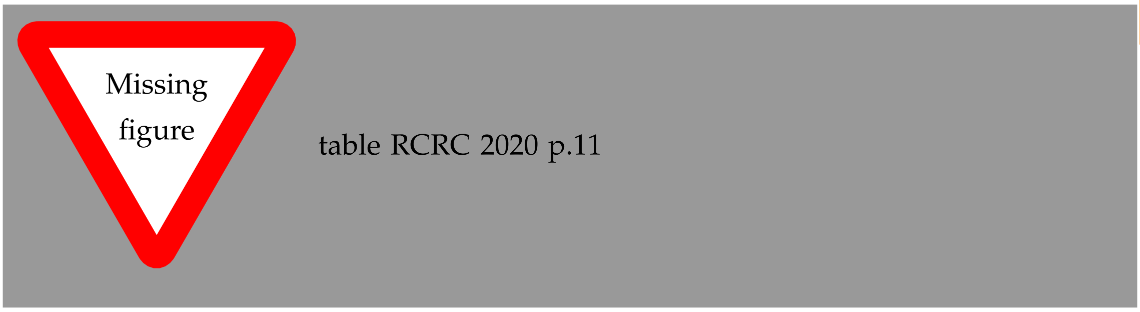

The *meteorological drought* is usually characterized by the duration and the degree of dryness in comparison to the normal average amount and tries to conceptually understand how weather patterns can impact water availability. Definitions in this category are specific for a regions atmospheric conditions. That is to say that regions with a year-round precipitations regime such as tropical rainforest need different definitions and thresholds than e.g. climates characterized by seasonal rainfall patterns (**nationaldroughtmitigationcenterTypesDrou**
Operational classification mostly uses rainfall, moisture, temperature and wind indicators to determine the onset, severity and duration of drought.

Agricultural drought definitions establish a connection between different features of meteorological drought with their impacts on agriculture. Soil-moisture, differences between actual and potential evapotranspiration and soil water deficits are some of the operationalized indicators for monitoring this type of drought (**nationaldroughtmitigationcenterTypesDrought**; Balti et al. 2020; Wilhite and Glantz 1985).

The type of *hydrological drought* is associated with the impact of meteorological drought on surface or subsurface water resources such as rivers, lakes, and groundwater. Hydrological drought occurs when these indicators drop below normal levels (Palmer 1965). The fastest responding indicator of this type of drought is most often the variability of streamflow. The water levels of lakes and groundwater usually lag behind the occurrence of the meteorological or agricultural drought which is why the hydrological drought is often out of phase with the previously mentioned types. The hydrological drought is commonly defined on the basis of watershed or river basin scale (**nationaldroughtmitigationcenterTypesDroug** Balti et al. 2020; Wilhite and Glantz 1985).

The *socioeconomic drought* differs from the aforementioned types as it can also incorporate features of these types of drought to associate them with the demand and supply of some social or economic good. It therefore relates the impact of all other types of droughts on human population and its various sectors of society such as food security, health, and the economy. It is therefore sometimes also interchangeably used with drought impacts. Operational categorization involves using socioeconomic indicators such as unemployment rates and food prices to assess the severity and duration of the drought (**nationaldroughtmitigationcenterTypesDrought**; Wilhite and Glantz 1985).

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https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx

The shown economic, social and environmental impacts of drought in figure depend on the severity of, and the risk to drought. These three concepts of impact, severity and risk are interrelated concepts used to assess and understand the effects of drought on various sectors. Thereby, in alignment with the definition of (Van Loon et al. 2016) it is the exceptional severity of the water shortage that distinguishes drought from aridity, an ordinarily recurrent or fully dry climate, and from water scarcity as a long-term "supply/demand and natural and/or human-made phenomenon" (IDMP 2022, p. 7; Nationen 2021; VAN et al. 2017). Water scarcity is described in more detail in the following chapter.

2.2.2 Water Scarcity

Water scarcity, as for water security or drought, is defined in many different ways. The sixth IPCC Assessment Report defines water scarcity broadly as "a mismatch between the demand for fresh water and its availability, quantified in physical terms" (Caretta et al. 2022, p. 560). Here, social and economic components are outsourced to the broader concept of water security and insecurity, focussing primarily on physical water scarcity (Caretta et al. 2022). In contrast, the Food and Agriculture Organisation of the United Nations (FAO) defines water scarcity as "a gap between available supply and expressed demand of freshwater in a specified domain, under prevailing institutional arrangements (including both resource pricing and retail charging arrangements) and infrastructural conditions" (FAO 2012, p. 5) further summarizing that water security is "an excess of water demand over available supply" (FAO 2012, p. 6). Thus, highlighting the human dimension of this interactive and relative concept of physical and economic water scarcity. Hereby, physical water scarcity refers to a situation in which there is not enough water available in quantitative terms to meet demand whereas economic water scarcity occurs when inadequate infrastructure, institutional or financial capital obstructs access to water resources "even though water in nature is available to meet human demands" (IDMP 2022; Molden, Institute, and Water Management in Agriculture (Program) 2007, p. 11). Water scarcity and drought are in a complex interrelationship with each other. A short overview about the key differences between water scarcity and drought are given in table .

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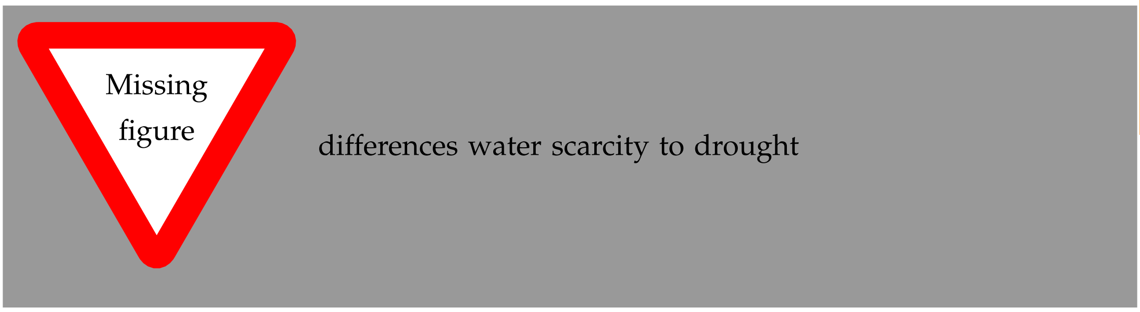


Furthermore, potential mutual reinforcements, climate change, increased water use and poor water management can make it sometimes difficult to clearly separate these concepts (IDMP 2022; Leal Filho, Totin, et al. 2022; Junguo Liu, Yang, et al. 2017; RCRC 2020). Nonetheless, following the definition of (FAO 2012) the concept of water scarcity always gives water shortage, understood as absolute lack of water in the current situation, a human dimension in particular on the demand side. Here, the quality of policies, planning and management is considered as critical to the overall severity of the impact of water scarcity (IDMP 2022; FAO 2012; Nationen 2021). The supply side can be influenced by human activities, but it is not a mandatory prerequisite. (IDMP 2022). Besides the already mentioned water scarcity on the basis of physical quantity and economical factors, water scarcity can also be caused by water of unacceptable quality and lack of access to water services (FAO 2012). The recognition that insufficient water quality is an additional contributing factor to water scarcity is a relatively recent development in the literature (Junguo Liu and Zhao 2020) but together with inadequate access highlights further challenges in ensuring water security (Caretta et al. 2022; Mishra et al. 2021).

2.2.3 Water Quality & Access

As could be seen in the previous chapter, besides the quantitative availability of water, its accessibility and quality are crucial. Inadequate water quality can be related to numerous health and environmental issues and can further limit the availability of water for given uses (RCRC 2020; FAO 2012). Unlike the previous concepts, water quality has mostly fixed indicators by which the condition can be determined but historically, and still today, water quality assessment is primarily carried out in laboratories with preceding water sampling activities. This procedure not only makes the determination of water quality a laborious and costly process, but also places high demands on equipment and personnel, so that it is not viable for large-scale rural assessments in low-income areas. (**worldmeteorologicalorganizationPlanningWaterqualityMonitoring2013**; Tariq et al. 2021). While simpler methods for in situ water quality monitoring exist, they are either insufficient or often still need too much investment and knowledge to conduct for widespread and frequent monitoring (**worldmeteorologicalorganizationPlanningWaterqualityMonitorin** Nonetheless, new solutions are being developed to simplify and scale affordable water quality assessments to rural areas (Ighalo and Adeniyi 2020; Tariq et al. 2021). While the direct assessment of water quality might be challenging, poor water quality can be linked to other factors. Environmental awareness, poor sanitation and hygiene conditions of people in rural areas were for example considered as major causes for contamination of water at the source (Zamxaka, Pironcheva, and Muyima 2004).

The definition of water access is again a rather challenging undertaking. The (Bank 1997, p. 254) defined water access in rural areas by "access implies members of the household do not have to spend a disproportionate part of the day fetching water." While both time and distance still play a crucial role in literature when investigating water access (Cassivi, Guilherme, et al. 2019; Cassivi, Tilley, et al. 2021; Emenike et al. 2017), the term also gained a social component (Emenike et al. 2017; Mitlin et al. n.d.). (Obeng-Odoom 2012) adds four additional factors namely, affordability, quality, equitable distribution to the definition of water access to fully understand if users have access to water in daily live. (Programme 2002) links these parameters to the access to an improved water source which should provide safe drinking water. The access to improved water sources is therefore generally considered as crucial in the reaching of water security (CDC 2022a). Proactive measures to drought and water scarcity can not only potentially minimize or even neutralize impacts and are considerably more cost-efficient, early warning and anticipatory actions for drought and water scarcity impacts become ever more important (UN-Water 2021; IDMP 2022; Bank 2016).

2.2.4 Measurement and estimation approaches for impacts

Indicators and Indices are often used to translate complex matters into easier to explain numbers and scales that can be measured, tracked and reasonably compared (Blauvelt 2014; Williams and Eggleston 2017). This can range from capturing simple measurements to complex and detailed issues that can not only depict ecological conditions but its interactions with societies (Blauvelt 2014; Mishra et al. 2021). Indicators and Indices can thus establish a clear and common understanding of a concept or parts of it in a quantifiable and more objective way. Here, an indicator is understood as a measurable parameter that provides information on the state or trend of an issue or problem. It can be a physical, chemical, biological, or socio-economic variable, such as temperature, soil moisture or streamflow and can be measured locally or remotely. An index is a composite measure that aggregates multiple indicators into a single value or score (United Nations University 2017; Williams and Eggleston 2017; Svoboda, Fuchs, and (IDMP 2016). Indices are commonly developed on regional or national level to account for the specific circumstances (United Nations University 2017). This case specification, together with different measurement and aggregation methods, partial inconsistency of definitions and differently focussed objectives on qualitative, quantitative, risk or impact scenarios can constrain their practical application and intercomparability (Svoboda, Fuchs, and (IDMP 2016; United Nations University 2017). Since there is no one definition of drought, water scarcity or security, there is no one best solution to the choice between the many indicators and indices for either of those.

Precipitation, evapotranspiration, soil moisture, lake and groundwater levels, streamflow and vegetation water stress are among the most prominent drought indicators (Observatory 2017). In order to adequately account for the different drought stages different drought indices, that aggregate these and other indicators, are applied. Among the most prominent meteorological drought indics are the Standardized Precipitation Index *SPI* together with its extension the Standardized Precipitation-Evapotranspiration Index *SPEI* (Observatory 2017; NCAR 2023a; NCAR 2023b). Agricultural drought indices like the Soil Moisture Anomaly *SMA* or the Anomaly of Vegetation Condition *FAPAR Anomaly* are based on soil moisture indicators and absorbed radiation fractions, respectively. By quantifying water flow volumina, the Low Flow Index *LFI* belongs to the hydrological drought indices (Observatory 2017; Svoboda, Fuchs, and (IDMP 2016). In addition to these and other types of indices, such as Combined Drought Indices, the *Handbook for Drought Indicators and Indices* lists over 50 drought indicators and indices. For further and more in-depth information, please refer to the interactive website of the IDMP launched by the World Meteorological Organization (WMO) and Global Water Partnership (GWP) (IDMP 2021).

All of these drought indices give a good impression about the physical side of climate anomalies, but none of the above mentioned indices link those climate anomalies to socioeconomic vulnerabilities (Enenkel et al. 2020). (Mishra et al. 2021) argue, that the framing of water security challenges extends beyond singular indicators. (Lackstrom, Farris, and Ward 2022) argue further, that assessments that only consider physical factors overlook the broader impact of drought on social, economic, and ecological systems. The simple but widely used Falkenmark Indicator (Falkenmark et al. 1989) incorporates human factors by calculating a ratio between the given amount of water and the number of people living within that domain. By further categorizing this ratio to a level of water scarcity, the Falkenmark Indicator indicates the supply sides effects of water scarcity but variabilities, demand and socioeconomic factors are not represented. More dedicated indices like the International Water Management Institute (IWMI) Indicator and the Water Poverty Index (WPI) as well as other indices measuring water security give a more extensive representation of the overall situation (Arreguin-Cortes et al. 2019; Junguo Liu, Yang, et al. 2017). The wpi for example represents the weighted average of five pre-standardized components namely, water availability, access, capacity, use and environment (Sullivan, Meigh, and Giacomello 2003).

Determining the right set of indicators and indices for a given region to e.g. assess hazard severity depends on the objective and available data and is often a balancing act between many factors and circumstances (Svoboda, Fuchs, and (IDMP 2016). Besides the pure description of what certain natural or social circumstances *are*, there is an growing interest to understand what these conditions will *do* (Boult et al. 2022; Lackstrom, Farris, and Ward 2022). The effects of these conditions on the ground are most often called the *impact* of a certain weather phenomenon or climate development such as a drought hazard. Impacts can be direct or indirect and a generally difficult to quantify economically (Nationen 2021). The level of impact is commonly determined based on the severity of the hazard, the exposure of the investigated elements and their respective vulnerabilities (Harrowsmith et al. 2020; Svoboda, Fuchs, and (IDMP 2016; Nationen 2021). This concept is generally expressed by the risk equation

$$Risk = f(Hazard, Exposure, Vulnerability)$$

where

$$Vulnerability = f(LevelofCopingCapacity, LevelofAdaptiveCapacity)$$

(Boult et al. 2022; Harrowsmith et al. 2020; Nationen 2021). Drought hazard can be evaluated and described by the above mentioned indicators and indices with difficulties lying in the contextualization and setting of the threshold levels to separate between fluctuations within the normal range and extreme events. Exposure is commonly defined as social, economic, cultural or natural assets, services or resources in places that could be adversely affected by a hazard (IPCC 2014). Exposed elements can be more ore less vulnerable to the hazard. Vulnerability conditions are determined by the sensitivity or susceptibility of a system, community or individual to physical, social, economic or environmental factors or processes (IPCC 2014). These conditions are often further described as the level of coping and adaptive capacities. Coping capacities refer to available skills and resources of systems, organizations or individuals to address, manage and overcome unfavourable circumstances (IPCC 2012). In the same manner, adaptive capacities relate to preparation, reduction and moderation of those impacts.

The establishment of a functional relationship between the hazard, exposure and vulnerability to its impact can be rather difficult for numerous reasons and is further discussed by (Boult et al. 2022) for interested readers. Moreover, all these factors change over time, so that the quality of the calculations depends strongly on the timeliness of the data basis (Harrowsmith et al. 2020).

Relatively recent approaches argue for numerous benefits and reasons for greater inclusion of local knowledge and community integration in these approaches (Balehegn et al. 2019; Dube et al. 2016; Ebhuoma 2020; Giordano, Preziosi, and Romano 2013; M. S. Grey, Masunungure, and Manyani 2020; Hermans et al. 2022; Mercer et al. 2012; Mutasa 2015; Nyetanyane and Masinde 2020; Nyong, Adesina, and Osman Elasha 2007). Another emerging area in scientific interest is the gender inequality of drought impacts (Acharya and Prakash 2019; Fanning 2018; Hiwasaki et al. 2015; Mustafa et al. 2015; Sachs et al. 2020; Sani and Scholz 2022). Although these topics are of great interest, they fall largely outside the scope of this particular work.

An understanding of the severity of droughts and their current impacts enables targeted responses, as well as to allow for the development of future predictions based on current conditions. In this context, recent efforts have increasingly emphasized proactive and forward-looking measures in disaster relief initiatives. The forthcoming chapter will explore this relatively recent shift in approach and its implications for improving drought management strategies.

2.3 FbF, EAP, AA Early Warning + trigger

Traditionally, disaster management efforts have primarily focused on long-term preparedness or post-disaster response, thus only providing assistance and relief to affected communities after a disaster has occurred (TODO: policy overview, hyogo framework [UNISDR], coughland et al 2015). The lack of standardized procedures for forecast-based actions led to disaster warnings often going unheard (Kolen, Slomp, and Jonkman 2013). In the context of increasing frequency and severity of natural disasters, coupled with the impacts of climate change, the need for a more proactive approach that can reduce the impact of disasters on vulnerable communities became apparent (E. Coughlan de Perez et al. 2015; Trisos et al. 2022). Nonetheless, financial resources were for the time being strongly directed towards post-disaster response and incentives to invest in new and complex scientific developments including relatively high uncertainties were limited (Erin Coughlan de Perez et al. 2016). This changed with the development and successful integration of several new forecast-based financing systems that utilized the opportunity gap between a forecast and the disaster to successfully reduce corresponding impact. Based on this, to "substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030" became one of seven global targets of the Sendai for Disaster Risk Reduction 2015-2030 framework (Erin Coughlan de Perez et al. 2016; **undrrSendaiFrameworkDisaster**). Today, large institutions have now specialized sections for the financing of Early Actions such as the Climate Risk and Early Warning Systems Initiative *(CREWS)* and the Global Risk Financing Facility *(GRiF)* to support and backup Early Actions (EAs) (**GlobalRiskFinancing**; CREWS 2023). Forecast-based Financing *(FbF)* has thus emerged as a promising approach to disaster management that enables proactive, timely, and cost-effective responses to disasters (E. Coughlan de Perez et al. 2015) (TODO: add FORECAST-BASED FINANCING An innovative approach ([pdf](zotero://open-pdf/groups/4773535/items/3C2CE7BS?page=1annotation=UKW

The International Federation of Red Cross and Red Crescent Societies (IFRC) together with the () and German Red Cross (GRC) have developed and improved the FbF programme to fund EAs since 2007 (IFRC and GRC 2019).

Figure 1 - FbF Diagram ([RCRC, 2020, p. 3](zotero://select/groups/4773535/items/UESIQTRJ)) ([pdf](zotero://open-pdf/groups/4773535/items/P5JPVZ97?page=3annotation=W3UC7H26))

Following (E. Coughlan de Perez et al. 2015; Erin Coughlan de Perez et al. 2016) the structure of FbF can be distilled down to: When forecast states that an agreed-upon probability threshold is exceeded for a hazard of a designated magnitude, then an action with an associated cost must be taken that has a desired effect and is carried out by a designated organisation. (Erin Coughlan de Perez et al. 2016, p. 2). Thus, the FbF approach involves three key components (1) triggering (2) pre-defined EAs and securing a (3) financing mechanism in advance (compare **??**) (TODO: Forecast-based Financing A new era for the humanitarian system ([pdf](zotero://open-pdf/groups/4773535/items/KQZXSWVN?page=1annotation= These components are summarized in an Early Action Protocol *(EAP)* (TODO: cite policy overview These three components are summarized in Early Action Protocols (EAPs). ([Forecast-based financing: A policy overview, p. 2](zotero://select/groups/4773535/items/35XBEGJ7)) ([pdf](zotero://open-pdf/groups/4773535/items/8YZAQB5L?page=2annotation=58UQZK6T))).

FBF has three ([pdf](zotero://open-pdf/groups/4773535/items/K89MIG2V?page=3annotation=PF946AET))

2.3.1 EAP and drought specifics

In the Early Action Protocol (EAP) triggers, actions to be taken and financing mechanisms are clearly outlined, thus summarizing and explicitly assigning responsibilities to the involved actors, ensuring that everyone understands their role and task in the event of activation (Rüth et al. 2017). This results in clear accountability and full commitment from all stakeholders, facilitating the timely and efficient implementation of the predetermined actions (Rüth et al. 2017). Two types of analyses, namely the identification of forecasts and the risk assessment, form the basis for specifying the trigger, affected regions, and selected actions in the *eap (see Figure **??**).

Figure 2 - EAP Validation Steps ([RCRC, 2020, p. 4](zotero://select/groups/4773535/items/UESIQTRJ)) ([pdf](zotero://open-pdf/groups/4773535/items/P5JPVZ97?page=4annotation=6WWVYXLT))

Both assessments are primarily based on historic data and experiences. To identify suitable forecast(s), various forecasts are compared and analysed in terms of their capacities and performance to predict hazards. This is done mainly through a historically grounded analysis. Ultimately, a specific impact threshold based on one or a combination of several impact-based forecasts becomes the basis for triggering actions. This trigger also depends on the outcome of the risk assessment, as the impact of the hazard is highly influenced by the risk on site (IFRC, RCCC, and GRC 2023b; IFRC and GRC 2019).

The risk assessment is a complex analysis that takes numerous factors on scales of the hazard, and its sub-hazards, exposure, vulnerability and together with its coping and adaptive capacities, into account (IFRC, RCCC, and GRC 2023b). Potential inputs depend strongly on the respective hazard and can range from records of historical events, housing location and building structures in the case of hurricanes and floods to social factors like income, demographics and school attendance. The objective being the identification of corresponding impact levels, thus determining the most effective actions and allocating resources as objectively as possible. Nonetheless, most of these parameters are proxies, as direct information about localized impact is seldom, outdated, of low accuracy or quality (IFRC, RCCC, and GRC 2023b).

Due to the majority of the implemented EAPs concentrating on fast onset disasters such as floods, hurricanes or strong rains, the FbF concept were primarily focussed and developed in this regard. Here, typically a sole trigger and its associated set of actions are established, emphasizing rapid responses, given that there is often less than 48 hours between the activation and the occurrence of the disaster. (RCRC 2020). Drought as a usually slow-onset hazard, on the other hand, pose unique structural challenges to the process of determining thresholds to trigger actions as impact builds up over time and is highly dependent on the context (Boult et al. 2022). These challenges of identifying a forecast, determining a trigger and seclting actions are further outlined in the coming chapters.

The specification of the financing mechanism as one of the three key components will not be covered in any further detail in this work, as the IFRC has extended their Disaster Relief Emergency Fund *(DREF)* with Forecast-based Action as dedicated mechanism to adequately support their increased numbers of FbF projects. Once the forecast-based trigger is met and the EAP is activated, the financing mechanism automatically assigns resources, which solves the issue of financing to a large extent and is therefore no longer of great interest to this piece of work.

2.3.2 Forecasts

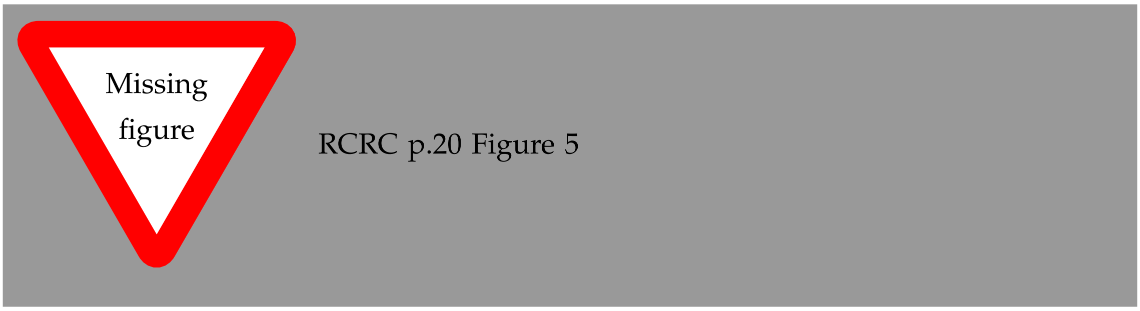
Indicators and indices as discussed in chapter 2.2.4 measure the severity, duration and spatial coverage of hazard conditions based on historical and current weather data. They provide a snapshot of current conditions and serve as an indicator of the overall situation. Forecasts, on the other hand, use these indices together with climate models and weather data to predict future conditions and provide early warning of potential hazard events. Thus, forecasts extend the retrospective and current measures of indices to future prediction. Similar to the indices, a single forecast usually only covers certain facets of a hazard. In the case of droughts, the thematic orientation commonly follows its definition classification into meteorological, hydrological and agricultural subdivisions. Furthermore, forecasts can additionally be categorized into global, continental or regional spatial scales with coarser scaling predictions mostly correlating with longer time spans and vice versa (Balti et al. 2020). Global to continental meteorological drought forecasts with the focus on seasonal or inter-seasonal predictions are often based on same scale phenomenons such the Julian-Madden Oscillation, the ENSO cycles or the Indian Ocean Dipole (Anderson et al. 2022; Gore, Abiodun, and Kucharski 2020; Yuan et al. 2008). These conditions are mostly collected through satellite and weather data often utilizing drought indices such as the SPI, SPEI and EDDI indices (Kim et al. 2021). Further drought prediction services such as the National Integrated Drought Information System of the US government, the European Drought Observatory (EDO) or its adaptation, the East African Drought Watch, utilize a wide range of different indices to predict hazard development and their impacts (Observatory 2017; ICPAC 2023; NIDIS 2023). These institutions also produce timely forecasts, but their data sources are usually based on the same remote evaluations mostly predicting what the weather and climate will be, and not what its implications on the ground will look like (Enenkel et al. 2020).

The transition to impact-based forecasts represents a radical shift in the way these forecasts are produced and opperationalized (IFRC, RCCC, and GRC 2023b). Practically, this would change the information that a forecast would provide from predicting e.g. precipitation patterns to e.g. the magnitude and spatial coverage of crop failure (Harrowsmith et al. 2020). The challenges of functional relationships, complex interconnected cause and effect networks and data availability mentioned in chapter **??** are also applicable here, but the change to impact-based information results in multiple benefits to practitioners nonetheless. Impact-based forecasts help with the identification and prioritization of areas and communities most severely impacted. They do this by supporting a transparent, evidence-based, sector- and context-specific decision-making process directly focussing the population at risk (IFRC, RCCC, and GRC 2023b).

(Boult et al. 2022) argue even further for an adapting and dynamic impact assessment process, as decadal shifts in climate variabilities, changing exposure and vulnerabilities are not incorporated in a pre-defined system. They propose a hybrid framework of multi-hazard forecasts interlinked with static vulnerability and dynamically adjusted with real-time expert vulnerability assessments. Threshold triggers are lower, where static vulnerabilities are higher. However, both the regular pre-defined impact forecast and the dynamic impact forecast must be preceded by a selection and definition of triggers and actions.

Trigger definition

Triggers are mainly combination of hydro-meteorological forecast combined with exposure and vulnerability data (RCRC 2020, p. 19). There are commonly two ways to define a trigger for early actions. On one side, triggers can be consensus-based, meaning experts make real-time judgements by synthesizing information from multiple sources, or on the other side, triggers are data-driven, peer-reviewed and validated well in advance of a potential event (RCRC 2020). Drought with its different layers of complexity may also benefit from a combination of these mechanisms, as e.g. the framework of (Boult et al. 2022) proposed above shows. Generally, good conditions for effective trigger development are sufficient historical data, knowledge about local livelihoods and how diverse parts of communities are influenced differently, thorough identification of differentiated impact drivers and their correlation to magnitudes as well as trustworthy forecasts (E. Coughlan de Perez et al. 2015; Erin Coughlan de Perez et al. 2016; Elisabeth Stephens et al. 2015; Harrowsmith et al. 2020; RCRC 2020). Furthermore, the framing and definition of the underlying forecast, indices and indicators are paramount as data-driven triggers are "specific values of an indicator or index that initiate and/or terminate each level of a drought plan and associated mitigation and emergency management responses. (RCRC 2020; Svoboda, Fuchs, and (IDMP 2016, p. 13). This specification is highly context specific and e.g. in the case of flood can be defined as the level when the river breaches its banks and inundates the surrounding area. Though, in another area this overflow may only inundate open space and thus lead to no impact at all (Elisabeth Stephens et al. 2015). This circumstance is relatively easy to grasp, has a single trigger and one set of specified actions such as evacuation, transportation and early warning and is therefore well integrable and implementable (see upper illustration in figure **??**) (Siahaan 2018).



Drought, due to its slow-onset and potentially cascading impacts that only builds up over time complexifies the process of trigger definition as Anticipatory Actions (AAs) to some impacts may go hand in hand with active responses in some areas and be to early in others. Furthermore, forecast certainty, granularity and accuracy all decrease the more one looks into the future (RCRC 2020). Deciding when to trigger is therefore a critical and challenging aspect of conceptualizing a drought EAP (see bottom illustration in figure TODO: RCRC p.20 Figure 5). Practitioners and experts interviewed by the (RCRC 2020) advocate for a staggering triggering system (.) Here, multiple triggers with different sets of AAs would extend the single trigger mechanism and give the opportunity to account for the different phases and the inherent complexity of the phenomenon drought. Moreover, the (RCRC 2020, p. 30) calls for the development of "unconventional triggers for ()" as the trigger development is not yet complete.

2.3.3 Anticipatory Actions

Anticipatory Actions are at the heart of every EAP and their execution is what everything is working towards. The goal of every Anticipatory Action is to help people and communities at risk to reduce negative impacts of a hazard. The final execution is preceded by some conceptual and practical steps. The establishment process begins with the identification of contextually meaningful, suitable and locally realisable actions with special focus on stakeholders, resources and available lead-time. These are further prioritized and selected based on the risk assessment, type and magnitude of hazard, and forecasting capabilities. When a first set of AA is defined, they are worked through in detail, reflected on with stakeholders and ultimately finalised. Together with an evaluation phase, this process is often a simultaneous and iterative process which also does not stop with the operationalisation of the EAP (Elisabeth Stephens et al. 2015; IFRC, RCCC, and GRC 2023d; IFRC, RCCC, and GRC 2023c; RCRC 2020). In practice, Anticipatory Actions are commonly split into a preparation and an activation phase. The preparation phase builds on the process described above, but also extends to actions that prepare for rapid activation, such as the prepositioning of water tablets before the rainy season (Elisabeth Stephens et al. 2015). The activation phase requires a constant operation of forecast monitoring and is initiated when the trigger is reached. Timely information dissemination, releasing and receiving funds, implementing of the AAs and subsequent evaluation are part of this phase (Elisabeth Stephens et al. 2015; IFRC, RCCC, and GRC 2023c). Often, AAs are not very different from response actions except of their predictive and proactive nature. However, this foresight comes with the cost of uncertainty and forecasts may not always be accurate. The simultaneous implementation of AAs in the absence of the disaster is commonly referred to as *to act in vain* (E. Coughlan de Perez et al. 2015). Besides financial costs, this may also manifest in reputational costs in e.g. the case of Early Warning and evacuation if false alarms occur too frequently (Elisabeth Stephens et al. 2015). Albeit, a growing body of evidence suggests that the benefits of AAs outweigh the costs substantially (Cabot Venton 2018; E. Coughlan de Perez et al. 2015; Gualazzini 2021). Furthermore, the issue of *acting in vain* can be lessen by staggering triggers and adjusting AAs in accordance with long-term resilience building (WFP et al. 2021). This can allocate the actions more precisely and increases the general benefits. (IFRC, RCCC, and GRC 2023d) makes these design adjustments the basis of its definition of *acting in vain* and thus argues for the abolition of this term, since the benefits of acting should always outweigh not acting at all.

2.4 Citizen Science, Crowdsensing, Volunteersensing, VGI, alternatively satellite image interpretation

The inclusion of local knowledge in the system of Early Warning and Anticipatory Action can result in many benefits as already mentioned in the end of chapter 2.2.4. Adapting knowledge and policies to local conditions and people as well as learning from them, strengthening autonomous responses and involving local stakeholders in all stages of the processes are just some of the potential ways to improve implementations (Giordano, Preziosi, and Romano 2013; IDMP 2022; Lackstrom, Farris, and Ward 2022; Leal Filho, Barbir, et al. 2022; Leal Filho, Totin, et al. 2022). One way to include local knowledge is through Citizen Science, very broadly defined as "public participation in scientific research and knowledge production" (Fraisl et al. 2022) . Historically, the first citizen science project was possibly the Christmas Bird Count run by the National Audubon Society in the USA every year since 1900 (Link, Sauer, and Niven 2006; Silvertown 2009). Since around 2000, the number of publications in regard to Citizen Science has risen substantially and has established itself as a vibrant area of scientific interest (Kirschke et al. 2022). As more and new thematic fields joined this area of interest, numerous approaches have been made to define Citizen Science more precisely (Haklay et al. 2021). Over 30 definitions were selected by (Haklay et al. 2021) to explore their ambiguity and extend the best practice principles and characteristics of citizen science established by the European Citizen Science Association (ESCA) (**escaTenPrinciplesCitizen2015**; ESCA et al. 2020). Different political, scientific or societal lenses along with a variety of focal points such as (1) biology, conservation and ecology, (2) geographic data and (3) social sciences and health related issues have all contributed to the concept of Citizen Science (Haklay et al. 2021; Kirschke et al. 2022). The first, natural research and conservation, is the orientation most frequently related to Citizen Science with overlapping concepts to community-based, volunteer and participatory monitoring. It has common interests with the second category of Volunteered Geographic Information (VGI) in topics such as crowdsourcing and data quality whereas the the third category mostly resolves around public engagement with intersections to CS in public participation (Kullenberg and Kasperowski 2016). In order to highlight the core of Citizen Science alongside the different disciplinary orientations of the research, different frameworks, guidelines and levels of participation have been designed.(Kirschke et al. 2022) created a three cluster framework of design principles around *citizen* and *institutional* characteristics, together with their *forms of interaction*. Within these categories (Kirschke et al. 2022) highlight various qualities and skills such as age, social status, motivation, knowledge and education of the contributing citizens, financial and human resources on the institutional side and the method and density of communication and feedback practices as important parts of interactions. Guidelines and principles further specify, expand and structure these broad topics to make them practically applicable in various contexts (**escaTenPrinciplesCitizen2015**; CitizenScience.gov 2023; ESCA et al. 2020; *EU-Citizen.Science* 2023; Fraisl et al. 2022; García et al. 2021; E. Minkman 2015; Pocock et al. n.d.; Skarlatidou et al. 2019). Citizen science projects can also be differentiated according to how engagement with participants is designed. This is referred to as the *levels of participation* and is commonly structured into four levels. Increasing in participation intensity, (Buckingham Shum et al. 2012) categorize them into (1) Crowdsourcing, (2) Distributed Intelligence, (3) Participation Science and (4) Extreme Citizen Science. Following this categorization, participants can be (1) 'sensors', (2) 'interpreters', (3) engaged in problem definition and data collection or even (4) part of the analysis. Depending on the level of participation and thematic orientation, Citizen Science is related to concepts of classic monitoring practices (1), transdisciplinary research emphasizing engagement of the public along the entire process (2 & 3) and participation involving "groups that are or perceive themselves as being affected by the decision" (3 & 4) (Buckingham Shum et al. 2012; C. C. Conrad and Hilchey 2011; E. Minkman 2015; Renn 2006, p. 1). Current challenges and limitations in Citizen Science projects are the complex demands in the conceptualization and design process with a wide range of required skills and resources, recruiting participants and sustaining their motivation, data quality and accuracy considerations, biases in collection and analysis as well as privacy regulations (Fraisl et al. 2022). Furthermore, research and CS projects are currently unevenly distributed on a global scale with an over representation of North American countries resulting in less experiences and guidelines for other areas and contexts (Kirschke et al. 2022; Zheng et al. 2018). Nonetheless, numerous studies suggest promising developments and application possibilities addressing all of the above mentioned challenges in design, participants and data related issues (Buckingham Shum et al. 2012; Budde et al. 2017; ESCA et al. 2020; Fraisl et al. 2022; Lowry et al. 2019; Pocock et al. n.d.; Rutten, Ellen Minkman, and van der Sanden 2017; Weeser et al. 2018).

2.4.1 Community-based monitoring

Community-based monitoring (CBM) is a sub-concept of citizen science and can be allocated to different layers of participation, depending on its definition, aspects and final implementation (Weston and Cathy Conrad 2015). CBM can encompass "a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track and respond to issues of common community concern" (Whitelaw et al. 2003, p. 410). The focus of CBM on monitoring is fundamental, but the monitored subject, further handling of the data and the involvement of the participants can vary widely (Baptiste et al. 2020; C. C. Conrad and Hilchey 2011; Koehler and Koontz 2008; Muhamad Khair, Lee, and Mokhtar 2021; Shirk et al. 2012; Weston and Cathy Conrad 2015). Within this work, CBM is understood as a combination of two main aspects. The collection part often refers to concepts of *Crowdsourcing* or *Crowdsensing* (see next Chapter 2.4.2) and a management aspect which promotes the incorporation of the generated information into community decision-making processes (Conrad 2007; Keough and Blahna 2006). Community-based monitoring can serve many purposes but its implementation and application is not always recommended. Therefore, many guidelines precede the design with an assessment of the feasibility of this approach (Association) 2015; CitizenScience.gov 2023; Fraisl et al. 2022; E. Minkman 2015; Pettibone et al. 2016). Here, the challenges, benefits and capabilities of the CBM approach are compared with the problem and core objectives of the project. It is emphasized that CBM should not be the goal itself, but only a means to fulfil the project goals (E. Minkman 2015). Nonetheless, the diversity of this approach means that other goals can be pursued and achieved apart from the main interests (see Chapter **??**). For example, enriching participants by addressing their needs, advancing their knowledge or teaching them new skills is considered as fundamental and important to achieving the main objective as it is to a successful project (Fraisl et al. 2022). In the following, a short overview about challenges, benefits and recommendations of CBM is given, broken down in the design phase, incorporation of participants and data concerns.

The conceptualization of CBM projects on the level of participation or the tripartite division according to characteristics of citizens, institutions and their forms of interaction have already been mentioned in connection with the broader concept of Citizen Science and are also applicable here. More concrete design factors and variables were synthesized by (Kirschke et al. 2022) but the systematic understanding of their influences on the success of remained unclear for now. A selection of subjects outside of the original research itself could be overall project management, communication in its various forms and with all stakeholders, community and participant recruitment, training and management, data management and analysis as well as the final implementation and operation of the project. Moreover, there is agreement that no *one-size-fits-all* solution exists and different goals, resources, and contexts have considerable influence on the design from project to project (Fraisl et al. 2022). In order to account for the variety of challenges and to maximize the benefits, staged frameworks have been developed to guide the design

(CitizenScience.gov 2023; Fraisl et al. 2022; García et al. 2021; E. Minkman 2015). Yet, these frameworks can be relatively coarse and imprecise and are often partly tailored to specific goals and contexts, making a combination of several such frameworks and the inclusion of further guidelines and recommendations potentially necessary to tailor the design to the specific situation.

Participants can take many roles in a CBM project based on the level of participation chosen but regardless of this, their adequate integration is seen as a cornerstone of any CBM project (Land-Zandstra, Agnello, and Gültekin 2021). Knowledge and skills as well as other socio-economic variables can vary widely between participants and it is important to account for this to inspire and keep participants motivated to contribute (E. Minkman 2015; Whitelaw et al. 2003). One mayor drawback of online collaborative initiatives is often that a considerable proportion of contributors only participate once and with minimal effort while a relatively small number of participants are responsible for the majority of the work (Sauermann and Franzoni 2015). Understanding and thus sustaining the motivation of participants is therefore central to a successful project. The subject of what drives individuals to participate in citizen science projects has been extensively explored in literature (**walkerBenefitsNegativeImpacts2021a**; Land-Zandstra, Agnello, and Gültekin 2021; E. Minkman 2015; Mloza-Banda and Scholtz 2018; Rutten, Ellen Minkman, and van der Sanden 2017; Tipaldo and Allamano 2017; D. W. Walker, Smigaj, and Tani 2021). Motivation can be intrinsic or extrinsic and spans from the will to contribute to science and conservation over meeting and helping other potentially like minded people to learning new skills and financial compensation (**rotmanDynamicChangesMotivation2012 ruttenHowGetI** E. Minkman 2015). According to (Rotman et al. 2012) study, egocentric motives tended to drive new participants, whereas established participants were more motivated by altruistic reasons, such as helping others. Furthermore, the individual adaptation of the task's difficulty to each participant was suggested to positively influence motivation in order to neither bore nor overwhelm (E. Minkman 2015). Other factors to inspire and sustain motivations are, among others, the expected benefits, acknowledgement and feedback culture and its perceived usefulness and integration into further processes (Land-Zandstra, Agnello, and Gültekin 2021; E. Minkman 2015; Pettibone et al. 2016). In addition to strengthening motivation, breaking down barriers to participation can also prove helpful. For this, understanding the background and circumstances of the participants is important. In their work for hydrological monitoring in Kenya, (Weeser et al. 2018) could partly attribute low participation rates to the transmitting costs of 0.01 USD per text message at some station. Offsetting these costs could subsequently increase the overall participation rate significantly. (Weeser et al. 2018) further discovered, that actual compensation or incentives appeared unnecessary as the intrinsic motivation of the participants proved to be adequate once financial constraints were addressed. Besides financial and resource restrictions, lack of knowledge and skills can be addressed by providing adequate training (Fraisl et al. 2022; Lackstrom, Farris, and Ward 2022).

Supervision, external or mutual feedback and preceding training of participants can also address common data quality concerns (Albus et al. 2020; Baalbaki et al. 2019; Fraisl et al. 2022). Besides the characteristics of the participant, the difficulty of the measurement task itself influences the quality. Simpler tasks such as gauging e.g. water levels provided high data quality in (Weeser et al. 2018) study. (Baalbaki et al. 2019) has further found that most of the data collected by citizen scientists is comparable to that of university scientists when it comes to chemical or physical qualities of water. (Albus et al. 2020) could support this finding, by analyzing data from the Texas Stream Team (TST) citizen science program and found an agreement of 80% up to 90% for DO, pH and conductivity parameters. However, (Baalbaki et al. 2019) also noted a disparity in the bacteriological test results between citizen and university scientists, to which they remarked, that it may be explained by the complexity of the testing process and the quality of the testing materials employed. (Aceves-Bueno et al. 2015) evaluated over 80 peer-reviewed studies of which only 11% reported no data accuracy issues but only one study reported, that the data was unusable. Based on the aforementioned findings, ensuring data quality and accuracy through appropriate quality assurance and control measures is crucial. However, despite the reliability and accuracy challenges associated with CBM data, (Aceves-Bueno et al. 2015) noted, that these issues typically do not have a significant impact on the data's overall usefulness.

Besides the more specific challenges and benefits mentioned above, Community-based monitoring approaches can benefit scientists, decision-makers, communities and participants in multiple ways. In addition to achieving the main objectives, raising awareness of the issue, the needs and the problems at hand, as well as increasing knowledge among all project stakeholders, can lead to changes in behaviour, improved management, reduced risks and a better representation of local conditions in the regional, national and international context. (Huang et al. 2020; D. W. Walker, Smigaj, and Tani 2021). Output quality can be enhanced when the objective is clear, participant involvement is recognized as a high priority, enough resources for design, implementation, operation and analysis are available and the monitoring protocol is not too complex (Butte et al. 2022; Pocock et al. n.d.). In an attempt to scale this concept across regions or even an entire country with many physical, social and economic differences, the CBM concept has been increasingly explored with mobile, network-enabled devices. This is, together with practical examples and projects, presented in the coming chapters.

2.4.2 Mobile Crowdsensing (MCS)

Originating in 2006 from an article by (Howe 2022) and Mark Robinson describing Crowdsourcing as a new internet based business model in the terms of "It's not outsourcing; it's crowdsourcing", by harnessing "the creative solutions of a distributed network of individuals through what amounts to an open call for proposals" (Brabham 2008, p. 76). Nowadays crowdsourcing in scientific contexts is often applied as e.g. act of "collecting data without a direct integration into the scientific process" by a generally large audience (Weeser et al. 2018, p. 1591). Due to the merely perceiving and transferring and not further interpreting character, *Crowdsourcing* is on the lowest level of participation levels. A more specific form of *Crowdsourcing* is *Crowdsensing* which refers to the process of measuring and collecting data by a large mass of contributors that involves using mobile devices and/or sensors to collect information about the environment. This is also known as Mobile Crowdsensing (MCS) (Guo et al. 2014; Jinwei Liu et al. 2018). MCS is part of a widespread transition in the way data is gathered and managed, with a shift away from conventional methods towards incorporating mobile devices, web platforms, and apps (Capponi et al. 2019; San Llorente Capdevila et al. 2020). This transition is being driven by the development and proliferation of information technology infrastructure, which includes the collection, sharing, storage, cleaning and analysis of data (Fraisl et al. 2022). These components of the information technology infrastructure can be grouped into a four-layer architecture which is described in detail in the paper by (Capponi et al. 2019). The first and top layer is the *application layer* concerned about high-level user, task- and overall design and organizational aspects with some examples being user recruitment's, scheduling and contribution management. The *data layer* as the second layer refers to storage, processing and analysis of the received data and is followed by the *communication layer* which refers to methodological and technological aspects of the reporting characteristics. These include cellular, internet or other networks and their means of transmission. The bottom layer, the centrepiece of this architecture, is the *sensing layer* which includes all tools, technologies and equipment involved in the data acquisition process (Capponi et al. 2019). Measurements can be of different types, intentional or unintentional, at the occurrence of an event or continuous, and are based on human observation, instrumental measurements or a combination of both (Zheng et al. 2018). In this architecture hierarchy, data flows generally from the lowest to the highest layer (Aceves-Bueno et al. 2015; Capponi et al. 2019; Zheng et al. 2018). Besides generally applicable challenges of Community-based monitoring such as data quality and participant motivation, main challenges of MCS are seen in the socio-technical, privacy and security realms referring to hard- and software availability, reliability and usability as well as balancing access rights, anonymisation and encoding with data trustworthiness (Aceves-Bueno et al. 2015; Alfonso and Jonoski 2012; Capponi et al. 2019; Jinwei Liu et al. 2018; E. Minkman 2015; Noureen and Asif 2017). Nonetheless, MCS also provides many opportunities and solutions to designers, operators and participants alike. Among those are the relatively good and easy scalability and increase of monitoring network density, low barriers for participation and two-way communication options as well as high potential for automatization and interoperability with other applications and frameworks (Alfonso and Jonoski 2012; E. Minkman 2015; San Llorente Capdevila et al. 2020; Weeser et al. 2018). In the following, practical examples of CBM and MCS or a combination of both are presented, highlighting the wide-ranging application possibilities.

Practical Examples of CBM and MCS

The potential applications for MCS, embedded in CBM or as a stand-alone project, are, as for all Citizen Science, wide-ranging and diverse. Besides the thematic diversity, the socio-technical implementation, size and complexity can differ substantially from project to project. Established networks like the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) founded in 1998 USA with over 25.000 observers facilitate the collection of daily weather observations and the sharing of written impact impressions via an online platform (CoCoRaHS 2023; Lackstrom, Farris, and Ward 2022). The Audubon's Christmas Bird Count (CBC) even goes back to the December of 1900 and in its 120th anniversary year over 81.000 observers counted more than 30 million individual birds (LeBaron and National Audubon Society 2022). Another major project in the realm of *Crowdsourcing* and MCS is the 2004 founded OpenStreetMap Foundation. Started as a reaction to the failed release of geographic information in the United Kingdom, OSM as a collaborative community effort quickly became one of the most important sources of geographic information world wide (**openstreetmapcontributorsOpenStreetMapBasemap2020**; Bennett 2010). Additional contemporary developments include the concept of MCS in citizen participation, Smart Cities, resource management, transport and behaviour evaluation and many more (DIPAS 2023; Commission 2021; H. Wang 2022). Other projects with a thematic focus on health, water and early warning are considered in more detail in the remaining part of this section. Health, as Community-based Surveillance (CBS) is successfully implemented as CBM with NYSS as MCS in Somalia (FIXME: see chapter **??**), and water and early warning projects, as they are thematically related to this work. Projects concerning VGI will not be discussed in depth in this context, as mapping in this project will most definitely be carried out by professional and trained personnel.

Community-based Surveillance

Conventional surveillance systems for monitoring health of animals, humans and the environment rely on information of medical professionals, health facility records, and laboratory examinations to detect abnormalities that could signify potential outbreaks and newly emerging pathogens (McNeil et al. 2022). However, these data are not sufficiently accessible in all regions of the world to allow adequate responses (McNeil et al. 2022; Nikolay et al. 2017). The strong developments and increasing availability of mobile technologies, the recognition of the value of local knowledge in health management, and recently reinforced by the COVID 19 pandemic, have led to an an increasingly widespread use of CBS (Kullenberg and Kasperowski 2016; McNeil et al. 2022). The (Technical Contributors to the June 2018 WHO meeting 2019) defined CBS as "the systematic detection and reporting of events of public health significance within a community by community members". With the growing importance of the *One Health* approach, these "events of public health significance" span across the domains of human, animal and ecosystem health (CDC 2022b). (McNeil et al. 2022) identified 60 different ongoing surveillance systems across five continents. These systems were covering the three domains either stand-alone or in combination, on different spatial scales and with different technical characteristics. However, all projects have used some kind of digital technology, with websites and smartphones as the most common vehicles. Furthermore, a high percentage of the surveyed projects have noted the usefulness of the CBS approach as it "improved community knowledge and understanding" (78%) and "earlier detection" (67%). This finding is supported by various other studies (Byrne and Nichol 2020; Jarrett et al. 2020; McGowan et al. 2022; Metuge et al. 2021; Ratnayake, Finger, et al. 2020; Ratnayake, Tammaro, et al. 2020; Technical Contributors to the June 2018 WHO meeting 2019). The CBS approach has proven to be a more advantageous complement to the conventional system, especially if certain conditions are taken into account. (Guenin et al. 2022) highlights the importance of congruent definitions and their adaptation to the different actors and roles as well as the adaptation of (two-way) communication channels. Preceding suitability assessments, simple design and reasonable incorporation of technology, effective community engagement, reliable and close surveillance through supervisors of local volunteers especially in the beginning as well as evaluation and feedback opportunities have been highlighted as key drivers for success. These drivers were grouped by (McGowan et al. 2022) in relation to (1) surveillance workers, (2) the community, (3) case detection and reporting, and (4) integration. Most of these factors and more have already been mentioned in the CBM context. They were linked to having a decisive influence on the quality of embeddedness in existing systems, acceptance, trust and ultimately its implementation in decision-making and response. In addition to these key success factors, main challenges remain in ethical and privacy considerations, availability of resources and fast response capacities in case of an event as well as community expectation management. Furthermore, (Boetzelaer et al. 2020) findings indicate, that the additional benefits of CBS in already stable settings are limited as the approach is resource intensive. Nevertheless, the increasing application of CBS in low-resource or conflict-affected areas, where the full range of benefits were brought to bear. These benefits include CBSs' early warning capabilities and showed promising capacities to address current gaps in health related information and response management, especially in regard to spatial coverage and lower response times (Metuge et al. 2021; Ratnayake, Tammaro, et al. 2020). (Metuge et al. 2021) has additionally been able to fruitfully adapt CBS for related issues such as displacement and malnutrition and the SRCS is currently using CBS together with the MCS platform NYSS from the Norwegian Red Cross (NRC) in Somalia.

NYSS is an open-source implementation following the MCS concept and is primarily developed by the NRC (**nrcNyssToolDeveloped2022**). The platform allows for high degrees of automatization in regard to data collection, storage, validation and analysis as well as feedback and notification possibilities.

In regard to law, privacy and data security, NYSS servers are located in Ireland and are therefore under European Union data protection law. Besides these law requirements,

NYSS has conducted a Data Protection Impact Assessment (DPIA) in 2020 (Quinn et al. 2020) which has generally attested to good standards and made some recommendations for further improvement. Additionally, (Quinn et al. 2020) highlighted that the "DPIA is an ongoing process" (p.57) which needs to be conducted regularly which goes in line with the general recommendations for CS evaluation practices. The NRC further conducted a recent evaluation of CBS and NYSS, but the report was not yet published at the time of writing.
While NYSS is developed and operated by the NRC, the data and most of the operations processing of personal user data is owned, overseen and controlled by the respective National Society. Though, no personal data is collected, stored and processed in NYSS (NRC and IFRC 2021).
The aim of developing NYSS was to provide a simple data collection tool for early warning, rapid reporting and fast response and not for larger data collection endeavours for e.g. the collection of forecast related ground truth data. Therefore, the current CBS collection and transmission functions via simple SMS and pre-defined codes. Thus, the collection is limited to these codes and their respective meaning. Nonetheless, due to this restriction to simple coded SMS, a normal phone and mobile network are sufficient for data collection. A smartphone and internet connection is thus not necessary. The codes have a specific order and are separated by ’’. In a single report, the code in the context of CBS consists of

$$healthrisk/eventsexage$$

where the health risk is represented by one number, sex is either male (1) or female (2) and age is categorized into 0-4 years (1) or 5 years and older (2). Aggregated reports are used in case of higher numbers and represent "a summary of several cases" (NRC and IFRC 2021, p. 35). Here, the order is decisive for the kind of information and the number represents the actual number of cases. The correctness of the code is automatically checked by the system and a feedback message is sent, also giving advice on how to react in regard to the specific disease, sex and age. The subsequent processing and potential escalation of the report can be seen in figure **??**.

https://www.cbsrc.org/what-is-nyss bottom image

This representation also shows the close involvement in regional processes for response purposes and the implementation of evaluation and supervision processes in the overall

structure. A dashboard with map and table views, displaying data collectors and messages facilitates further supervision as well as the fast and simple escalation of warnings to health officials and other organizations through an integration of other organisations (NRC and IFRC 2021; NRC and IFRC 2023). This high level of automation and good integration into existing organisational structures and actor networks enables rapid responses, often in less than 24 hours (Jung et al. 2022).
Technically, NYSS is primarily coded in C and JavaScript based on a Microsoft Azure storage solution. The SMS are received and via a physical SMS gateway and asynchronously processed by an internal bus communication system. The receiving functions are structurally separated from the reporting functions and connected via internal API requests. The parsing and validation takes place in the internal ReportAPI and the feedback SMS is sent via a data collector forwarding the message to an email-to-sms service which sends the information back to the volunteer (NRC 2023; NRC and IFRC 2021; NRC and IFRC 2023). The source code, together with the documentation, is open source and available on GitHub (NYSS and its infrastructure and architecture documentation.)

Community-based Water Monitoring and Management

Community-based Water Monitoring (CBWM) is an application example of CBM which gained mayor public interest particularly in North America, Europe, Australia and Southeast Asia (Kirschke et al. 2022; Koehler and Koontz 2008; Canada, T. G. Foundation, and WWF-Canada 2018). CBWM practices range from small monitoring projects to integrated partnerships or councils for the management of watersheds (Weston and Cathy Conrad 2015). Just as for CBM and CBS, participant engagement, data quality control and management, sustainable funding and embedding in existing structures are key to successful integration and implementation of such projects (Allen 2018; Canada 2018; Weston and Cathy Conrad 2015). An overview of primarily water and weather related citizen science projects can be seen in table **??**. Striking is the already mentioned globally unequal distribution of the projects with a strong emphasis on North American Countries. Furthermore, their focus is mostly on river, lake, groundwater and precipitation levels or focusses on their respective water quality. The technical solutions are mostly not freely available and not open source (FIXME: true? -> and extend).

Missing figure

overview table about water related CS projects with CBS/MCS aspects

Further noticeable are the technical requirements, which almost always require some sort of smartphone, dedicated measurement equipment or internet access. Only Weeser et al.'s approach is based on simple text messages but were limited in content to a station ID and the indicated stream water level. Here, signs explaining the monitoring and transmission process with pictures and instructions in Swahili and English were placed next to a water level indicator, encouraging passers-by to contribute (Weeser et al. 2018). (Weeser et al. 2018, p. 1597) noted, that method of "transmitting the observations using simple cell phones and text messages turned out to be stable and reliable without major technical problems" in the context of their work in low-income rural areas in Kenya. The problem of occasionally insufficient network coverage was overcome by participants waiting until they reached a network before transmitting, making network availability not a limiting factor in this study. (Wilson-Jones and Rivett 2012) established and evaluated an Android mobile based system to support rural water quality monitoring in South Africa by simplifying connection between managers and operators of municipal test facilities. While all municipalities expressed the system as beneficial exemplifying the usefulness of fast, easy and low resource-intensive communication possibilities in such a context, this project does not necessarily fall within the sphere of CS, as the target group here was professional staff. Drawing on their literature review of water quality studies under climate change, (Huang et al. 2020, p. 147) recommend the application of a "hybrid modality in which community management is the mainstay with supplement from external support" also considering differences in local realities and stakeholder opinions and needs.

One approach to embed into local traditional community water management practices is proposed by (Day 2009). (Day 2009) argues, that overarching concepts like the Integrated Water Resource Management (IWRM) remain to large and complex to be manageable and implementable on local levels and additionally often fail to adequately include local stakeholders. Building on the decentralized and locally better opperationalisable version of IWRM called 'light IWRM' (John Butterworth et al. 2010; Moriarty, J. Butterworth, and Batchelor 2004) and its practical component of Water safety plans (WSP) (Bartram 2009), (Day 2009) created a community-based water resource management framework (see figure **??**).

TODO: Figure 2. Community-based water resource management ([Day, 2009, p. 59](zotero://select/groups/4773535/items/YWSNQ8A2)) ([pdf](zotero://open-pdf/groups/4773535/items/ETPCI5RI?page=14annotation=BAMSY255))

This framework provides the foundation for monitoring by encompassing the specifics of arid regions also with regard to possible drought phases, community needs, risks and water resource assets. Furthermore, the community is seen primarily as a partner rather than a beneficiary, also taking into account internal communal heterogeneity and inequalities making it a good conceptual basis for this works water source monitoring design approach. The usefulness and practical applicability of this framework is presented by (Oxfam 2009), as they make this framework the basis of their community-based water resource management implementation guide for field programmes in dryland areas. Further work for guiding principles in the sphere of CBWM are numerous and interested readers are referred to (Weston and Cathy Conrad 2015).

Other community-based concepts and initiatives

Potential capabilities and areas of application to apply the concept of CBM and MCS are wide-ranging and numerous. Besides health- and water related domains, Community-based Disaster Risk Reduction (CBDRR), Disaster Risk Management (CBDRM) and Early Warning Systems (CBEWS) / information dissemination are rising fields of application. While health and water-related projects can be part of the broader CBDRR or CBDRM approach, depending on their focus, many projects about CBDRR, CBDRM and CBEWS focus on natural disasters such as droughts, fires, typhoons, (flash) floods, and landslides (Macherera and Chimbari 2016; Manalo 2013; Pineda 2015; Smith, Brown, and Dugar 2017; Tarchiani et al. 2020; Trogrli and van den Homberg 2018; Vhumbunu 2021). Based on (UNISDR 2009), (Vhumbunu 2021, p. 198) defines CBDRM as "the involvement of potentially affected communities in disaster risk management at the local level by building their capacities to assess their vulnerability to natural disasters and develop strategies necessary to mitigate the impact of these disasters" and further states, that "at the core of these concepts is the involvement of communities in making decisions and implementing disaster risk management strategies, actions, and initiatives". Examples for participatory Disaster Management Software are large and multi-purpose platforms like Ushahidi, Sahana Eden and Kobo (Organization 2023; S. Foundation 2016; Ushahidi 2023). A smaller but dedicated approach to bridge indigenous knowledge and modern science by disseminating early drought information and warnings is the framework ITIKI (Information Technology and Indigenous Knowledge with Intelligence) (Akanbi and Masinde 2018; Masinde 2014; Masinde, Bagula, and Muthama 2013; Masinde, Mwagha, and Tadesse 2018; Masinde and Bagula 2010; Masinde and Bagula 2012; Masinde and P. N. Thothela 2019; Nyetanyane and Masinde 2020; P. Thothela et al. 2021). This system integrates scientific and indigenous drought forecasts by combining local and expert knowledge, technical components like wireless sensors, mobile phones and artificial intelligence analysis capacities to provide micro-level forecasts to local farmers and communities. Positive effects of local drought forecast dissemination could also be confirmed by (Andersson et al. 2020)'s (FIXME:) study while also mentioning, that local capacities or preconditions often limited a positive respond to the early warning. (FIXME: check if this is correct)(Gladfelter 2018; Inayath 2018; Trogrli and van den Homberg 2018) highlight the importance to tailor the information to the needs, capacities and social structures of communities on the ground to enable their successful implementation. Accounting for

community heterogeneity is also emphasized by (Gladfelter 2018) as people may be incapable to respond to early warnings due to a lack or resources or knowledge. In addition, (Inayath 2018, p. 21) advocates that early warning messages should be "simple, timely, and encourage early action" to enable an appropriate response in the first place. Another problem in implementing participatory early warning systems is the gap between classical top-down approaches and community-based bottom-up initiatives. Successfully bridging the gap between these two approaches by directly coordinating available technical capacities through a participatory approach is possible according to (Tarchiani et al. 2020). This is supported by (Henriksen et al. 2018) findings, that bottom-up approaches in contrast to classical concepts better facilitate the integration of local stakeholders in processes of decision-making and risk management.Generally, (Marchezini et al. 2018) literature review indicates a shortage of research in regard to citizen science and CBEWS and (Baudoin et al. 2014) additionally notes the need to significantly improve the design and application of early warning systems. (Baudoin et al. 2014) advocates for an integrated cross-scale approach ensuring the involvement of the at-risk population at all stages of the management process. Further arguing for "early warning systems that are both technically systematic and people-centred" (Baudoin et al. 2014, p. 15).
The CBS approach together with the MCS NYSS application has thus shown that CBM and MCS can be successfully applied to the local context and adapted to other topics as shown by the CBWM and CBDRR approaches. More on the regional implementation in sections 2.5.5 and 4.3.5.

2.5 Case Study Area (+ application of the rest)

Northern Somalia, also known as Somaliland, is a region located in the Horn of Africa. Officially referred to as the Republic of Somaliland, it is a self-declared independent, de facto sovereign state, but it is not recognised internationally and is still considered part of Somalia. Somaliland is bordered by the Gulf of Aden to the north, Somalia to the east, the Federal Republic of Ethiopia to the south and west, and the Republic of Djibouti to the northwest. The claimed region encompasses around 177,000 km^2 and has an estimated population size between 4.2 to 5.5 million people, depending on the source (**somaliredcrescentsocietyFeasibilityStudyPotential2022**; Petrucci 2022; Somalia 2021). Administratively, Somaliland according to international standards, Somaliland is divided into 5 regions, from east to west and north to south, Awdal, Woqooyi Galbeed, Todgheer, Sanaag and Sool with the capital being Hargeisa in Woqooyi Galbeed (see figure **??**) (Somalia 2021). Somaliland's own constitution divides the country into 6 regions where Woqooyi Galbeed is further divided into Maroodijeex (Hargeisa region) and Sahil (Somaliland 2019).

Somaliland figure with all the fancy stuff plllllls

This chapter will give a brief overview about the geography, economy and social conditions. It will place the above concepts in the context of past and present local conditions and elaborate on current work on early warning concepts and projects.

2.5.1 Geography & Climate

The geography of this region is marked by its arid and semi-arid conditions, with a diverse range of physical and environmental features that define its landscape. Topographically, Somaliland can be divided into three main zones: the coastal plain Guban, the mountain range Oogo and the plateau Hawd (Somalia 2021). The Guban (Somali for 'the burnt') area is a very hot and arid region averaging less than 100 mm rainfall per year with potential evapotranspiration exceeding rainfall by thirty times (Salem 2016). Furthermore, it is not unusual to have no rain at all for 2-3 consecutive years. The Oogo mountain ranges receive up to 500-600 mm of rainfall annually with equal evapotranspiration potential, and annual mean temperatures of 20-24 řC, with peaks rarely exceeding 35 řC. Temperature conditions on the Hawd plateaus are comparable, but precipitation can be lower and the potential evapotranspiration is at a factor of about 1.5 (Abdulkadir 2017; Salem 2016). Somaliland's climate is typically arid to semi-arid and experiences four distinct seasons. The primary rainy season, known as Gu', takes place from April to June and contributes to about 50-60 % of the annual precipitation. The secondary rainy season, called Dayr, lasts from August to November and accounts for approximately 20-30 % of the total rainfall. The remaining two seasons are Jiilaal and Xagaa, which occur from December to March and July to August, respectively, and are characterized by dry conditions (Abdulkadir 2017; Somalia 2021). A detailed description of the geological features of Somaliland, together with many pictorial impressions can be found in (Petrucci 2022). The soil types in Somaliland are closely linked to its geomorphology and are typically marked by poor structure, high permeability, low capacity to retain moisture, and insufficient internal drainage (Salem 2016). The naturally sparse vegetation, tree cutting and overgrazing also lead to accelerated soil erosion (Salem 2016). Nomadic and transhumance pastoralism activities influence around 90 %, and agro-pastoralism about 2 % of the land with often adverse environmental effects (Salem 2016). Besides poor soils, high levels of erosion and a challenging climate, little water resources stress the local fauna, flora and human population.

2.5.2 Water Sources

Often insufficient knowledge about hydrogeological conditions and access depths of more than 100 m caused a very limited number of boreholes, approximately 300 in Somaliland (FAOSWALIM 2012; Petrucci 2022; Salem 2016). As there are no permanent rivers in Somaliland, the use of surface water is primarily based on water retention structures storing part of the water supply beyond the rainy season (Petrucci 2022). Wide and open structures called *balleys* can store large volumes of water, but do not last as long as *berkads*. Traditional berkads are commonly 3 to 4 meters deep, 7 to 9 meters wide and 10 to 13 meters in length. Build materials are commonly stones and clay and some are covered with organic materials such as sticks and bushes. Berkads are generally constructed in clusters and usually built on a slope to collect water during the rainy season, but are sometimes filled by man-made canals with or without impurity collection facilities (R. Walker and Sugule 1998). These missing mechanisms during the filling process can result in contamination of the water with organic matter, animal or human faeces etc. (Corps 2017). The same lack of separation of animals and humans can also lead to contamination when water is extracted. Improved designs exist and more sophisticated versions nowadays use concrete, are properly roofed to counteract evaporation and have adequate inflow and extraction mechanisms to prevent contamination (Corps 2017; Petrucci 2022). Following (Corps 2017) calculations, an improved berkad needs to have a volume of about 1000 to 1200 cubic meters to withstand a 3 month dry period with a monthly extraction of 288 m^3. This amount would serve 240 persons (20l/day/person), 150 camels (12l/day/camel) and approximately 2000 (1.5l/day/animal) sheep and goats. Currently valid total number of Berkads for Somaliland do not exist but (R. Walker and Sugule 1998) estimated about 12.000 berkads clustered in 126 groups in the ethiopian district in Gashaamo, which borders Somaliland in the south. (**birchWeUsedSing2008**) notes 7000 berkads for the Hawd region, although with an unknown number of non-operational berkads. The sheer number and reliance of pastoralists and communities on berkads mentioned by (R. Walker and Sugule 1998) and (Birch 2008) illustrate their importance. Besides boreholes and berkads, shallow wells, springs and dams are types of water sources. Available datasets about all water sources but especially berkads, concerning e.g. their location, functionality, status of ownership and other factors are limited, mostly outdated and unknown in quality (*FAO SWALIM: Somalia Water and Land Information ManagementFAO SWALIM: Somalia Water and Land Information Management* 2022).

2.5.3 Political, social and economic circumstances

After being ruled by the Ottoman Empire and subsequent British colonisation, Somaliland gained independence on 26th, June 1960. A few days later Somaliland voluntarily merged with Italian Somalia to form the Somali Republic. From 1969 until 1991, Somali Republic was controlled by a military junta, led by Siyad Barre which from a supremacy of the southern part cruelly and partly arbitrarily suppressed the northern one, Somaliland. Arrests, mining of water points and executions culminated in the genocide of thousands of members of the largest clan, the Isaaq tribe (Peifer 2009; Somalia 2021). Since the collapse of the Siad Barre regime in 1991, Somaliland has developed into one of the most politically stable democracies in the Horn of Africa, but challenged in recent times due to the postponement of elections (BBC 2022; Forti 2011). Though, internel conflicts and border disputes with Puntland in the east continue until today (Filho and Motta 2021). Nowadays, Somaliland is a presidential republic, combining its traditional clan culture with modern democratic elements and structures of the House of Representatives and Elders (Salem 2016). Somaliland has a GDP of approx. 1.5-2$ billion, mostly based on remittances from Somalilanders working abroad and main export being livestock, per capita income is only in the hundreds of dollars (Klobucista 2018; Somalia 2021; Bank 2014). Low literacy rates (48% for adults above 15), a 35% secondary school education completion rate and high unemployment rates further complicate the situation (Somalia 2021; Bank 2014). Due to its reliance on pastoralism and livestock for mayor parts of its economy and food security, Somaliland is prone to natural disasters (**usaidcenterforresilienceEconomicsResilienceDrought2018**).

2.5.4 Hazards and risks

Drought, flash floods, land degradation and conflict all pose risks to Somaliland's environment and society, with droughts posing the greatest threat in recent centuries (Abdulkadir 2017). Several historical and current analyses and predictions indicate, that these phenomena will not get less but possibly intensify and become more frequent driven by large phenomena like the El Niño-Southern Oscillation and rising Sea Surface Temperatures (SST) (Abdulkadir 2017; Ali and Jemal 2017; Balint et al. 2013; Erian et al. 2021; *FAO SWALIM: Somalia Water and Land Information ManagementFAO SWALIM: Somalia Water and Land Information Management* 2022; Musei, Nyaga, and Dubow 2021; Committee 2022; Trisos et al. 2022). Population growth, deforestation and desertification, groundwater depletion and land grabbing further stresses the situation (Ali and Jemal 2017). While a rough tendency can be derived from such predictions, (Abdulkadir 2017, p. 10) findings indicate, that the forecast quality of global climate model simulations "show varying results and therefore remain uncertain for Somaliland". Geographically, the eastern regions Sanaag, Sool and Todgheer are historically the most severely impacted ones (Abdulkadir 2017; *FAO SWALIM: Somalia Water and Land Information ManagementFAO SWALIM: Somalia Water and Land Information Management* 2022). In the period since 1960, Somaliland experienced 17 major droughts with the most intense and widespread droughts in 1973-1974, 1984, 1991, 2010/2011, 2016/2017 and 2021 until today (Abdulkadir 2017; CRED 2023). The worst drought in 2010-2012 led to a famine, where more than 200.000 people died and over 2.6 million people were affected all over Somalia (SRCS 2021). Currently, the almost complete failures of five successive rainfall seasons, rising food prices and severe water shortages are adding up to another stressful situation putting 810.000 people in need of emergency assistance (Committee 2022). This number is projected to rise substantially if the current drought conditions persist

(Swanson et al. 2022). Shallow wells and most Berkeds have dried up, leaving boreholes and expensive water trucking as the last options for water supply (Committee 2022). Cascading droughts can have cascading impacts as affected people are forced into bad feedback-loops to respond to the immediate crisis, reducing their coping capacity and thus further increasing their vulnerability to future events (USAID 2018). (USAID 2018) hypothesised, that these post-shock impacts can better be mitigated by early interventions than by late response. Although, (USAID 2018) states, that there is very little data to support this statement and that it is primarily based upon logical deduction and not field data. Nonetheless, this assumption is also supported by (Ali and Jemal 2017), (Abdulkadir 2017) as well as by the growing Forecast based Financing practitioners (Gualazzini 2021; Harrowsmith et al. 2020)

2.5.5 EAP + forecast, trigger and so on

The 2011 famine in Somalia was projected 11 month in advance. Despite this early warning, the international community failed to react adequately and in time to prevent the worst (Elisabeth Stephens et al. 2015; Hillbruner and Moloney 2012). Subsequent evaluations point to two main areas of concern. On the one hand, there was a lack of timely funding, but on the other hand, the concept of preventive action had not yet permeated the humanitarian community and response activities were still seen as the standard (Elisabeth Stephens et al. 2015). This failure, as well as the successive improvements in forecasting and the growing scientific interest and knowledge about the positive impact of early warning and anticipation measures, laid the foundation for the current development of the EAP for Somalia. As the project is still in progress, detailed information is not yet possible to present in all areas and the presented information is also subject to constant changes and future developments. Nevertheless, critical points for this work can be derived and the need for further developments can be elaborated.

The interest to develop an EAP for a slow-onset hazard such as drought only recently started to become more popular within the RCRC as the focus laid on fast-onset disasters thus far (RCRC 2020). (RCRC 2020) presented the first adaptation of the general manual of the IFRC (see (IFRC, RCCC, and GRC 2023a)), merging experiences of pilot projects to adjusted guidelines for the development of FbF and early actions in the context of drought. Currently, at least seven National Societies (Kenya, Uganda, Ethiopia, Zimbabwe, Somalia, Lesotho and Niger) are planning, developing or have recently completed a drought EAP (L. R. C. Society and IFRC 2022; N. R. C. Society and IFRC 2021; RCRC 2020). The Somalia Red Crescent Society (SRCS) has completed their preliminary *Feasibility Study on Potential Use of Forecast-based Financing (FbF)* in June 2022. A pilot study shall be conducted to test practical implementation feasibility in

Somaliland and potentially Puntland with emphasis on, from highest to lowest priority: droughts, health, (flash) floods, cyclones, locusts, and conflicts. Besides the detailed description and justification for each type of disaster, the assessment also confirmed the well positioning of the SRCS to undertake such a FbF program and to embed it into the general Disaster Risk Management. The implementation of a FbF program cannot be done by a National Society alone. Besides the SRCS numerous other stakeholders will take part in providing information, resources or knowledge as well as acting upon aforementioned. The landscape of actors is wide and includes many local, regional, national and international governmental and non-governmental groups, initiatives, centers and organisations. To name but a few: The Ministries of Agriculture (MoA), of Water Resources (MoWR), of Health Development (MoHD) and of Humanitarian Affairs and Disaster Management (HADMA) and others include Somaliland's state actors. (TODO:)Building Resilient Communities in Somalia Consortium (BRCiS) and Somaliland Community Disaster Risk Management Committees (CDRMC) compromise local and regional NGO networks and committees. The UN (FAO, OCHA, UNDRR, WFP, WHO, World Bank, WMO, GRC, NRC and IFRC are a selection of international actors engaged in Somalia. Added to this are a number of other think tanks, climate centres and forecasting providers, making the integration of the respective actors an important but also intricate affair, especially in the light of the multi-faceted nature of droughts(**somaliredcrescentsocietyFeasibilityStudyPotential2022**; RCRC 2020).

Forecasts are also provided by various organisations and scales. The FEWSNET releases famine warnings and reports for the entire african continent on a regular basis (FEWSNET and USAID 2023). Regional forecasts are provided by the Climate Predictions and Applications Centre (ICPAC) based on global models for the Greater Horn of Africa region (ICPAC and WMO 2023). More small-scale prognoses are released from FAO's SWALIM and FSNAU programs which monitor different drought indicators based on relatively few weather stations (100 manual and 10 automatic in all of Somalia) and remotely gathered and modelled climate information (**somaliredcrescentsocietyFeasibilityStudyPotential2022**; FAOSWALIM 2014). There are two other local seasonal forecasts issued by government agencies and disseminated by the responsible agency, NADFOR to stakeholders at all levels for natural hazard warnings (**somaliredcrescentsocietyFeasibilityStudyPotential2022**). Besides SRCS's own disease CBS informing actions for health related issues, data of local circumstances influence forecasts only scarcely and infrequently.

Up to this point, it has not yet been decided which prediction and reaction trigger should be chosen for the SRCSs' EAP but it will inevitably be based on scarce coverage and primarily large scale data, as it is the case for the EAPs in Niger and Lesotho (L. R. C. Society and IFRC 2022; N. R. C. Society and IFRC 2021).

The trigger methodology will be a staggered trigger, following current recommendations of the (RCRC 2020) but its definition remains a challenge due to the currently very tense situation and the medium-term changes in weather and climate over the last 10 years. Under these conditions, it is quite difficult to determine a *normal* period against which *drought events* can be measured and will ultimately depend on the chosen forecast. Conceivable triggers could be the predicted failure of one or more consecutive rainy seasons or a specific classification warning for food or water insecurity but will also depend on selected actions. (Gettliffe 2021, p. 19) found, that triggers need to be linked to their respective intervention, or otherwise will "led to significant challenges". Identified actions by the feasibility study for the EAP for drought interventions are water storage rehabilitation, de-stocking, early or alternative short growth crop planting, cash distributions, women and children shelters as well as water trucking (**somaliredcrescentsocietyFeasibilityStudyPotential2022**). The Ministry of Livestock and Fisheries Development notes, that de-stocking will hardly be feasible due to little trust in forecasts by livestock owners as well as no internationally approved abattoir which limits the amount to local market capacities (**somaliredcrescentsocietyFeasibilityStudyPotential2022**). (Gualazzini 2021) propose water voucher as viable alternative to water trucking in regions where a functional market of private water vendors already exists. Besides AAs, adequate policies for water management, price regulations, and allocation mechanisms are seen as potential opportunities to mitigate further drought impacts (Gualazzini 2021; W. Wang et al. 2016). Besides the mentioned forecasts of natural phenomena, SRCS has successfully set up a CBS project developing and utilizing the platform NYSS to monitor and react to disease outbreaks on community level since 2018 (Jung et al. 2022).

Besides SRCS and IFRC, OCHA and BRCiS also developed anticipatory action plans for Somalia in recent years. OCHA followed with their pilot study in 2020 conventional frameworks in regard to forecasts and triggers, using large scale indices with a combined trigger of pre-identified thresholds (Gettliffe 2021; OCHA 2020). Chosen actions comprise all major fields of food security, WASH, education, health and risk communication, often with lead times of multiple weeks to months. In their evaluation, (Gettliffe 2021) synthesized many lessons learned in all areas. Highlighting the buy-in of all stakeholders, early expectation setting, the importance for parallel development of AAs together with explicit, linked and robust trigger mechanisms. Cash transfers were "identified across several clusters as the preferred action" where local markets and the operational context allow (Gettliffe 2021; OCHA 2020, p. 21).

BRCiS created their own Community Real-Time Risk Monitoring Systems (CRTRMS) to integrate local information. The CRTRMS is based on key informants from a selection of a small group of 2-3 communities which represent a larger population of 10-12 communities. These information are then triangulated with regional, national and international secondary information sources to ultimately propose relevant anticipatory measures. The survey together with the triangulation should allow triggering within 12 days after data collection but commonly averages on 25 days in practice. Besides the relatively long duration, key informants are well aware, that their given information may influence the amount of humanitarian assistance in the area, highlighting the importance of trustbuilding and data triangulation(Gualazzini 2021). Indicators and thresholds are categorized into *normal*, *alert*, and *alarm* allowing for *red-flagging* of areas based on either one very strong impact or on a pre-defined amount of cumulative impacts in multiple areas. For example, one indicator is the condition of primary water sources in communities. These are assessed at the end of rainy season and categorized based on their water level into normal *(more than half-full [75%] or full)*, alert *(half-full [50%])* or alert *(less than half-full [25%] or empty)* which allows for a seasonal prediction and corresponding flagging.

2.6 Summary Literature

This chapter outlined the overall theoretical background of the case studies context by starting with wide ranging and complex concepts such as Water Security, Water Scarcity, Drought and their respective indicators and indices subsequently narrowing them down to the actual case study area and the problem at hand.

Relatively new approaches to mitigate, instead of focus on post-disaster response was described in the concept of Forecast based Financing and respective sub-parts. The FbF approach is based on impact forecasts which predict what the weather will do, instead of conventional forecasts that predict what the weather will be. Based on this knowledge, protocols can be developed which specify the exact threshold to trigger corresponding Anticipatory Actions to counteract impact of the disaster. To facilitate this, the knowledge needs to be highly local and relevant to the specific action. Citizen Science, together with its sub-divisions of Community-based monitoring and Mobile Crowdsensing was introduced and practical examples with Community-based Surveillance and Community-based Water Monitoring further exemplified its area of application. In this context, several other CS projects were identified and their characteristics elaborated.

In the last section, the previously presented concepts were broken down to the concrete case study area. The case study area was described in detail in terms of its physical, social, political and economic conditions and the development of the EAP development overlying this project was delineated.

Chapter 3

Methodology

The research design starts with the philosophical foundation of the methodology applied in this work. The chosen research type, its justification and methods are outlined thereafter. The main conceptual frameworks along with their integration and adaptation to the research question are subsequently described and contextualised. Several guidelines and recommendations from various other studies and projects are also presented. A summary of the key elements concludes this chapter.

3.1 Research Design

Positivism, historically emerged as a combination of rationalism and empiricism by french philosopher Auguste Comte, highlights the objectivity of knowledge and emphasizes the fundamental need for verification through observations. Positivism was, and often still is, mainly linked to quantitative research methods such as experiments and surveys, highlighting the independent and objective nature of scientific research. In contrast, interpretism (sometimes also called anti-positivism), often equated with qualitative methods such as participant observations and unstructured interviews, argues that objectivity is largely impossible and all knowledge is subjective in nature. Both of these more extreme approaches were increasingly criticised at the end of the 20th century. Emerging concepts like post-positivism, for example, acknowledges biases and discusses the idea that while truth cannot be objectively proven, false claims can be rejected (Pelz 2023; Trochim and Donnelly 2001). This work, applied both deductive and inductive perspectives on quantitative analyses and theory testing of conducted programs, projects and literature to synthesise best practices and guidelines. It also applied interpretive methods like interviews to gain new expert knowledge about the context and realities of the case study to build new theory. Therefore, a combination of both approaches will be reflected in a mixed-method approach which benefits of both, quantitative and qualitative data.

The research type that "allows for in-depth, multi-faceted explorations of complex issues in their real-life settings" (Crowe et al. 2011) is the *case research* or often just called *case study*. This definition goes back to (Yin 1984) and highlights the core strengths of this approach. The research type of the case study is particularly well suited for exploratory, rather than for descriptive or explanatory research, closely examining circumstances within a specific geographical area and context (Zainal 2007). Here, various quantitative and qualitative forms from both historical and real time data can be investigated and examined directly in its given context (Fitzgerald 1999). This allows for a detailed, multi-perspective and specific investigation of that particular topic of interest, which might not be given when examining the parts individually (Pelz 2023; Zainal 2007). Yet, case studies also comes with a number of trade-offs. More extreme critics see the case study method only as a loose 'story', which in the worse case is even connected to the scientist himself (Fitzgerald 1999). This criticism refers to the lack of rigour and "very little basis for scientific generalisation" which can lead to low external validity (Yin 1984; Zainal 2007, p. 5). The internal validity often remains weak due to no or poor experimental control complicating causal relationship testing and the multifaceted nature of case studies make it dependent on the researcher and prone to bias and some kind of subjectivity. Besides the internal and external validity, constructed validity and reliability need to be accounted for. Constructed validity refers to "the extent to which a study investigates what it claims to investigate" (Gibbert, Ruigrok, and Wicki 2008, p. 3) so that "the researcher can correctly evaluate the studied concepts" (Ferreira, Andrade, and Almeida 2020, p. 277). It can be addressed by establishing a clear chain of evidence and triangulation of perspectives and sources (Gibbert, Ruigrok, and Wicki 2008). Repeatability by other scientists using the same methodology to arrive at the same insights is termed 'reliability'. Repeatability refers therefore to the "absence of random error" and can be enhanced by clear procedures and good documentation (Gibbert, Ruigrok, and Wicki 2008, p. 5). Furthermore, case studies are frequently criticized for being excessively long, challenging to execute, and requiring significant documentation efforts (Yin 1984). Alternative research types such as experimental research, desk or field surveys and survey research also all have their inherent advantages and limitations. For example, experimental research often deductively examines cause-effect relationships in an isolated context, making it strong in internal validity but low in external validity as the often artificial isolation does not reflect the real world (Pelz 2023). Survey research, as another example, has a variety of advantages, such as measuring unobservable data (e.g. peoples preferences, beliefs and values), it is easily scalable and can be carried out independently of time and space. Nonetheless, it is also subject to many biases such as sampling bias, recall bias and non-response bias (Pelz 2023). Since all research types have their advantages and disadvantages, it is primarily a weighing of these strengths and weaknesses that determines the choice of method. The strength of the case study make this research type ideal for a holistic exploration and understanding of novel and under-researched areas within a "complex and dynamic context where it is difficult to isolate variables or where there are multiple, influencing variables" (Fitzgerald 1999, p. 2; Zainal 2007). Therefore, a case study is an excellent method not only to test theories but also to develop new theories and frameworks, as it is the aim of this (pilot) study (Pelz 2023; Zainal 2007).

Along with the exploratory technique, an iterative technique was adopted, referring to the "visiting and revisiting [of] the data and connecting them with emerging insights, progressively leading to refined focus and understandings" (Srivastava and Hopwood 2009, p. 77). Thereby, each interview or questionnaire was directly transcribed, coded, analysed and merged with the insights gained up to that point. Along with the conducted literature review this approach verified previous findings and iteratively expanded the insights. Together with the theoretical background information and project analyses, newly acquired knowledge could be iteratively evaluated, triangulated, integrated and used as a basis for further research and interviews. This made it possible to check, deepen and refine the knowledge gained piece by piece.

The background analysis started with the review of the already established database of the overarching EAP development and was subsequently extended. Broad concepts were used as a basis to lay a thematically large, yet steadily more specific foundation. For the in-depth analysis of previous CS projects and further insights into the case study itself, grey and peer-reviewed literature was consulted. Grey literature, as academic literature specifically on Somalia was found to be generally scarce. The search was based on different combinations of keywords and their synonyms which could be derived from the underlying concepts and their respective specifications. Furthermore, in the course of the work, more specific literature and project suggestions were received from the project team and the interviewees. For the selection of CS projects, core areas of interest were formulated and derived from the thematic focus of the fundamental concepts. Therefore, the thematic focus was on community-based participatory environmental or risk monitoring, but always with a focus on water related issues. The geographical location, size or technical facilities had no influence. Subsequently, the projects were tabulated and jointly evaluated manually, since the absolute number of projects finally selected was manageable at 20 without additional software.

Available data about water sources in Somaliland was analysed via QGIS3. The data was taken from the spatial FAOSWALIM. Four data sets about water sources in Somalia, a settlement layer and administrative boundaries. All layers were projected to WGS84 / UTM zone 38N and subsequently clipped to the boundaries of Somaliland. The following analysis of the data was primarily exploratory, and extended with a statistical analysis of basic parameters.

In addition to the thematic focus on water-related issues, the practical implementation on the ground was investigated by analysing the already established CBS program of the SRCS. This was done primarily by interviewing the responsible managers. The selection of interviewees was based on a strategy of targeted expert sampling, i.e. a non-probability method that focused on reaching key informants and conducting expert interviews. This technique was employed as the expertise and experience of the individuals was crucial rather than focusing on broad, generalisable statements (Pelz 2023). This method was further extended by adopting a snowball sampling approach which helped to identify further stakeholders and potential candidates.

The target persons were primarily people who know the local context and/or are potential stakeholders in a possible implementation of the design in question. The first interview came about through existing contacts of the project in which this work is embedded, and the interviewee was the project leader of the FbF approach in the SRCS (I1). In the further course, the CBS project manager on the Norwegian Red Cross side (I2) and the CBS manager on the Somali side (I3) were also interviewed. Between these two interviews, there was a second interview with the project manager of the SRCS' FbF team (I1.2). More interviews with representatives of the Ministry of Water Resources, NADFOR, FAOSWALIM, BRCiS and the technicians responsible for the NYSS platform were envisaged (TODO: see appendix XYZ for the questions) but could not be conducted. The interviews with the project leader on the SRCS side unfortunately had to be replaced by written questionnaires, as he could not free up time for an interview and only the higher flexibility of the online questionnaire allowed him to contribute at all. For the conversion of the interview guidelines into questionnaires, the recommendations of (Harkness et al. 2016) were followed. The interviews and questionnaires themselves were semi-structured and mostly consisted of open ended questions to allow for the interviewee to give a free response as opposed to predefined answer options (see appendix TODO: **??**). Open-ended questions can facilitate more detailed answers, new insights and overall allow for an unlimited response in terms of scope and focus while they also complicate relevant information abstraction and following analysis (Pelz 2023). The intelligent verbatim transcription of the interviews was facilitated by the newly developed neural net called Whisper (OpenAI 2022; OpenAI 2023) and subsequently checked and corrected in MaxQDA 2022. For the further analysis, the recommendations of (Rädiker 2020) were followed. The coding strategy followed an inductive, open thematic manual coding approach. Codes were not strictly predefined, to be able to appropriately incorporate newly gained expertise, but only broadly categorized into the main themes of interest. More dedicated coding approaches based on e.g. the grounded theory or the hermeneutic analysis were not applied, as the given information was the focus of interest and not e.g. the identification of subjective constructs and underlying meaning (Pelz 2023). Nonetheless, based on the criticism on positivism, provided information was not taken as unbiased and objective but interpreted in the context of its perspective.

3.2 Design Frameworks

The design of the roadmap for participatory community water source monitoring is particularly guided by two mutually complementary design frameworks. The six iterative stages for the design and implementation of a Citizen Science project in environmental and ecological sciences by (Fraisl et al. 2022) will lay the conceptual foundation for this work. It covers the entire life cycle of a Citizen Science project in its six phases in an iterative way, starting with problem assessment and finishing with evaluation procedures. Before the actual application of the framework to the main research question, all six stages are first adapted and extended to the research question and the study area.

Stage three, the "designing the project" stage, will further be enhanced by a self developed requirement focussed framework, the Project Requirements Catalogue (PRC), to expand the process-oriented SSF and reduce cognitive overload (see section 4.2). The catalogue follows the structure of the SLMC and incorporates the recommendations of other guidelines as well as gained knowledge through the literature review and the project analysis. The original version of the utilized frameworks, the SSF and the SLMC, followed by a section about several other guidelines will be presented in this section.

3.2.1 6-Stage-Framework

In their work, (Fraisl et al. 2022) pull information from all kinds of CS programmes, projects and scientific guidance. While their thematic orientation is on projects in the field of ecology and environmental sciences, the underlying principles which they describe are successfully applied in a wide variety of other thematically differently oriented projects (Fraisl et al. 2022). The developed Six-Stage Framework (SSF) concentrates on the participation level (1) Crowdsourcing and (2) Distributed Intelligence. On these levels, citizens are primarily contributors and partly asked to interpret the sensed information. This was outlined in chapter 2.4. All six stages are interconnected and should all be considered throughout the project to incorporate new information, feedback and lessons learned (Fraisl et al. 2022). An overview of the *citizen science project life cycle* can be seen in figure **??**

ssf design - possibly do it myself as the figure is not as nice here (too much other stuff)

In stage 1 the overall need and problems are identified and their boundaries defined. This includes the gathering of potential solutions, limitations and the formulation of research questions. Stage 2 closely examines the potential application of CS in the identified boundaries. The focus is on the fruitfulness of the involvement of participants to reach the formulated objectives and answer the research questions. This may be related to many project specifications, e.g. temporal and spatial scale, required expertise and intended target groups. As the second major consideration for the reasonable integration of CS participants, (Fraisl et al. 2022, p. 2) note, that the project need to benefit the participants by "addressing their needs or fostering new skill and expertise". After problems, needs and applicability are addressed, the objectives and aims of the project need to be defined in detail together with the prospective participants in stage 3. In addition to the main objectives, secondary objectives such as awareness and knowledge building as well as its transfer could also be pursued. Concerns of privacy and ethics, data storage

and analysis, selection of methods and training strategies as well as means of communication and respective instruments are also parts of this stage. Furthermore, the tasks of the participants need to be defined in detail, also including any benefits and safety considerations. Stage 4 is concerned with the building of the community by identifying participants motivations, education levels and other demographic information as well as issues of acknowledgments, feedback and sustaining participation. Planning of data management in terms of collection, storage, Quality Control (QC) and Quality Assurance (QA), analysis and privacy and security are highlighted in stage 5. Although evaluation is the main theme of stage 6, it is seen more as an ongoing effort that is recommended throughout the project to allow for feedback and improvement at each stage.
TODO: adjust this

3.2.2 Seven-Layer Model of Collaboration

The design pattern of the SLMC was utilized to develop a new requirement focussed catalogue to guide the development of the SSF in stage 3 *designing the project* and onward to better handle and structure the high complexity of the roadmap design. The SLMC was specifically designed to reduce cognitive (over-)load for the design of a complex, interrelated project in a social-technical context. It does so, by separating concerns at design time into seven layers and corresponding methods and techniques. These, as presented by (Briggs et al. n.d.), are primarily aimed at the collaboration of groups, but the overall pattern can be preserved when applied to designs in other contexts (Diggelen and Overdijk 2009). Therefore, the following explanations of the individual layers, their methods and techniques are adapted to this work, while maintaining the general pattern developed by (Briggs et al. n.d.). The seven, slightly adjusted layers are, Goals, Products, Activities, Methods, Techniques, Tools and Scripts (see figure **??**).

slmc all layers figure -> beware of the Methods adjustement

The layers are ordered hierarchically with Goals being the top-most layer. Changes made in one layer, may need to be accounted for in the lower, but not necessarily in the upper, layers. The *Goal-layer* incorporates all overarching goals and objectives of the project. The *Products-Layer* sum up all tangible or intangible components or outcomes that are necessary to achieve the formulated targets in the *Goal-Layer*. The required activities that yield these products, are grouped in the *Activities-Layer*. These activities formulate what needs to be done to reach the goals and can have sub-products and sub-activities of their own. The fourth level is the most different from the original, as it does not deal with the procedures of cooperation but with the applied methods during the activities. The *Techniques-Layer* specifies the involved techniques and practices and the *Tools-layer* summarises all relevant artifacts or apparatus used. The final procedures are described in detail and defined in the bottommost layer, the *Script-Layer*. Further concerns, interactions and justifications between and for each layer are extensively described by (Briggs et al. n.d.) and while there is a lot of value in these remarks, the thematic adaptations and focus of this work make further exploration in this context obsolete. Nonetheless, interested readers are invited for further independent exploration. In this work, emphasis is given to the top three layers, the *Goal-, Products-, and Activities-Layer*.

3.2.3 Citizen Guidelines and Recommendations

Practical recommendations, frameworks and guidelines for Citizen Science projects have become numerous and thematically wide-ranging. Networks and programmes of researchers and practitioners covering all or parts of the stages proposed by the SSF are spatially widespread at the global level and include a variety of regional, national or global application levels. Some examples of such networks and programmes are government programmes such as the US-run citizenscience.gov website or the EU platform eu-citizen.science, support platforms such as CitSci and the Citizen Science Center Zurich as well as regionally focused associations like La Red Iberoamericana de Ciencia Participativa (RICAP), CitizenScience.Asia and the Citizen Science Africa Association.
Besides these knowledge-hubs, a vast variety of different scientific and and grey literature exists. (Fraisl et al. 2022) and (Weston and Cathy Conrad 2015) have each listed and summarized many of recommendations and (García et al. 2021) even created a guide to citizen science guidelines. Furthermore, (E. Minkman 2015) derived a set of six potential goals which could be addressed through Citizen Science in water management namely (a) awareness raising, (b) public education, (c) policy development, (d) method improvements, (e) knowledge building, and (f) management improvements. The boundaries between the individual goals can be fluid and are not set in stone. Each CS project can address multiple of these goals and with varying emphasis. These goals were derived in cooperation with water management authorities in the Netherlands and concentrate on objectives that can be implemented in practice. Although the overall objective of this work was already defined, all these six goals were chosen as a starting point for further analysis in order not to overlook potentially useful secondary goals. These six goals formed the first level of the SLMC in the development of the . Further emphasis was given to the findings of the BRCiS network and IFRC's CBS and FbF guidelines, manuals and recommendations. Further information of the above-mentioned projects, programmes, associations and others was integrated by extracting the key findings and guidance from the respective papers and projects, categorising them along the stages and then merging them with the SSF. The augmentation of both the theoretical and empirical underpinnings of this endeavor has served to enhance its overall depth and rigor.

3.3 Method Summary

Based on the philosophical ideas of interpretism and post-positivism, this chapter presented the methodological framework this work utilised. Embedded in an primarily inductive design type of an exploratory, iterative case study, a mixed-method approach with data and document analysis as well as expert interviews was adopted. In case of the interviews, non-probability together with snowball sampling was applied. The transcribed interviews were subsequently coded facilitating an open thematic coding strategy. The final design was guided by the 6-stage-design for Citizen Science projects in ecological science by (Fraisl et al. 2022) and further deepened by the Seven-layer Model of Collaboration of (Briggs et al. n.d.). Moreover, multiple other guidelines for the creation of a CS program were consolidated and their recommendations taken into account. The advantages, disadvantages and main limitations of these approaches were outlined and will be further discussed in the following chapters.

Chapter 4

Design and Application

The design of the roadmap along with the Project Requirements Catalogue (PRC) and its subsequent application for implementing the research aim is presented in detail in this chapter. As usual in the research design *case study*, this results-centred chapter will also have small parts of further explanations and conclusions, as the results partly build on each other and evaluations had to be made in the intermediate steps to allow further continuation. Nonetheless, these parts were kept to the bare minimum, leaving major discussions to the next chapter.
In the first section, the SSF is adjusted and expanded to the given case study area and its context (compare section 3.2). By applying the SLMC (see section 3.2.2) on all previously gained knowledge, guidelines, projects, and conducted interviews a PRC was developed in the second section of this chapter to better support the process-oriented design roadmap from the third phase onwards. The last section will apply the extended SSF along with the PRC to the actual research question in the context of this case study.
The full interview and questionnaire transcripts are presented in Appendix **??** and the protocol to the data analysis in Appendix **??**. The chapter concludes with a short summary containing the main findings.

4.1 Design Roadmap

The stages follow the Six-Stage Framework (see section 3.2.1) and are presented in the coming sections. The design of the roadmap is primarily based on the SSF but additionally incorporates several other CS project guidelines and experiences, information from the conducted interviews, and the wider literature. While the stages conceptually separate the design process, it is important to keep in mind, that the stages are interconnected and "one step does not necessarily need to end for another to begin" (Fraisl et al. 2022, p. 2). Stages 1 outlines the exploration phase to establish a first understanding of the problem, context and potential solutions. The second stage elaborates on how to conduct a feasibility study to evaluate the CS approach regarding the identified problem in the given context. When the feasibility of the CS approach is confirmed, the overall structure of the project is laid out in Stage 3 *Designing the Project*. This stage describes the usage of the gathered information of stage 1 and 2 to further specify the research goal, respective products to reach these goals and the activities that constitute to the products. More guidance is given to which other data needs to be collected, assessed and integrated to lay a good foundation for the coming stages. Stage 4 is concerned about topics surrounding community building efforts and Stage 5 outlines concerns in regard to data management. The last stage, *Stage 6 Evaluation and Iterative Improvements* underlines the importance and elaborates on the practical implementation of ongoing assessment and improvement measures.

4.1.1 Stage 1: Context and Problem identification

This first stage is the exploration phase of the overall project (CitizenScience.gov 2023). This is where the environment of this project is established, in which itself is embedded. It is aimed at identifying prevailing conditions in all areas that may be covered or touched by the project. Even if this stage does not go into too much detail, the identification efforts must be thorough and as complete as possible. Oversights in this stage can have serious consequences in later stages. To enable this identification, project boundaries must first be defined by the overall objective and the problems to be solved, which also take into account challenges, positive and negative constraints as well as resource requirements. In addition, potential key stakeholders should be involved from the beginning and comparable projects and datasets need to be carefully identified and analysed to avoid duplication. (CitizenScience.gov 2023; Fraisl et al. 2022; E. Minkman 2015). Based on this information, possible solutions can be derived and hypotheses or research questions formulated (Fraisl et al. 2022; Silvertown 2009). Additionally, evaluation practices and sustainability considerations should be integrated into the project as early as possible although they are only defined in detail at a later stage (Fraisl et al. 2022).

4.1.2 Stage 2: Assess the feasibility of the Citizen Science approach.

The Citizen Science approach is not feasible for all kinds of projects. Certain criteria should be met and the feasibility of design, implementation and operation must be ensured and tailored to the decision-making processes that the project aims to influence. Fundamentally, a CS a project must contribute to achieving the defined objectives and solving the problems, while also providing benefits to the participants, e.g. in terms of knowledge, community or recreational value (ESCA (European Citizen Science Association) 2015; Fraisl et al. 2022). The feasibility assessment needs to consider various factors and constraints in more detail than in stage 1 to identify information and management gaps accordingly. The goal should be clarified along with potential sub-goals and related products which need to match the derived gaps and the capacity of the implementing organisation (IFRC 2017; E. Minkman 2015). This organisational capacity depends on financial, human and technical resources, knowledge and experiences, embedding in decision-making networks and structures, and the organisational commitment and dedication of those involved. (Fraisl et al. 2022; IFRC 2017). The importance of securing (long-term) funding is also highlighted by many guidelines (Cervoni, Biro, and Beazley

2008; E. Minkman 2015; Sharpe and Cathy Conrad 2006; Whitelaw et al. 2003). Existing datasets and potential tools need to be analysed and assessed for suitability. In addition to the positive constraints, the (IFRC 2017) has defined negative *red flag* constraints which, when they occur, should stop further design developments until they can be resolved appropriately. These *red flags are:*

- A need does not exist
- The community does not want the project
- Barriers and fears of: information usage, data sharing, applied technology and different cultural beliefs
- Insufficient capacities regarding financial and human resources, knowledge, experience and phone coverage
- No support of key stakeholders
- No or insufficient response possibilities

4.1.3 Stage 3: Designing the Project

This stage builds on the identified context and conditions of stage 1 and the feasibility study of stage 2 and creates the broader framework for more specific work in stage 4, 5, and 6. The goals and research questions are considered again and finally specified and formulated in alignment with the projects, participants and stakeholders interests and aims (C. C. Conrad and Hilchey 2011; Fraisl et al. 2022; E. Minkman 2015). Previous assumptions should be backed up as much as possible and made explicit (Silvertown 2009) and biases need to be addressed (ESCA (European Citizen Science Association) 2015; Fraisl et al. 2022). "Legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities" need to be considered (ESCA (European Citizen Science Association) 2015). The design need to be thoroughly embedded in the context and anchored by policies, preferably in an Integrated Water Resource Management initiative (Cervoni, Biro, and Beazley 2008; Sharpe and Cathy Conrad 2006) and ongoing FbF implementations and efforts. The 'light' IWRM *community-based water resource management* framework by (Day 2009) is recommended as a starting point as it is geared towards practical feasibility (see section 4.2.2). The integration into the FbF is done by targeting data management (stage 5) on indicators which support intended triggers and respective anticipatory actions (IFRC 2017). Adequate and scientifically justified thresholds and monitoring methods may need to be developed and triangulation data sets identified, assessed and integrated.
A structured interconnected foundation needs to be created for the integration of community building (Stage 4), data management (stage 5) and evaluation and iterative improvement procedures (stage 6) in the current project. Community building encompasses recruitment, training, task specifications and participant benefits, motivations, feedback

mechanisms and stakeholder acknowledgements. It is also concerned with the broader frame of partaking and collaborating non-governmental organisations and government bodies at all levels (C. C. Conrad and Hilchey 2011). Data management practices should be oriented on already proven concepts of comparable projects, identify and define data collection, transmission, storage and analysis aims, formats, and types (Fraisl et al. 2022; Gualazzini 2021; IFRC 2017). Consideration also needs to be given to the ways in which the new data from this project can be publicly displayed, accessed and used to improve completeness, timeliness and overall quality of information and decision-making processes (Catherine Conrad 2006). Evaluation and iterative improvement procedures are concerned with pre-defining success metrics which should be considered during the entire project design and operation.
In this third stage, the project requirements catalogue presented in the coming section 4.2 is recommended for integration to reduce mental load in the further design process.

4.1.4 Stage 4: Community Building

This section pertains to the identification and establishment of all relevant factors associated with the participants, community, network, and organizational and governmental decision-makers. Understanding participants characteristics and motivations as the primary data collectors and contributors to the project is detrimental to the sustained success of the project. Their characteristics include, among others, the educational level, skills and demographics (Cervoni, Biro, and Beazley 2008; Fraisl et al. 2022). The motivation aspects comprise elements of interests, engagement, acknowledgements and overall gained benefits. The first set of characteristics can be addressed by training, supervision and provision of feedback, especially for new participants (ESCA (European Citizen Science Association) 2015; Fraisl et al. 2022; E. Minkman 2015; Sharpe and Cathy Conrad 2006). Providing feedback to the actual contributions but also in terms of how the contributions influence planning and management decision-making processes and outcomes can positively influence the motivational aspects (Catherine Conrad 2006; C. C. Conrad and Hilchey 2011; Whitelaw et al. 2003). Creating wider public engagement and interest can further enhance motivational factors such as recognition and community building (Catherine Conrad 2006). Community events and networking bring further social benefits, trust and belonging and open up opportunities to engage directly with decision-makers and make them aware of what this project is and why it exists (Catherine Conrad 2006; Fraisl et al. 2022; Sharpe and Cathy Conrad 2006). Decision-makers, such as respective water and risk related government ministries and agencies, should be integrated in the process and design right from the beginning as especially local and regional leaders can help to implement and operate the project on site (Gualazzini 2021; IFRC 2017). They can furthermore help to sensitize the community, manage expectations and inform about and support in dealing with oppositely motivated stakeholders (I1). (Catherine Conrad 2006) encourages the perspective of integrating the project into the management as an opportunity and not as a threat. Inclusion of legal and ethical guidelines should also happen in this stage, but has its focus in the upcoming stage 5 (Fraisl et al. 2022; IFRC 2017; E. Minkman 2015).

4.1.5 Stage 5: Data Management

Legal and ethical laws, guidelines, and standards especially in terms of privacy and data security need to be respected. This also includes taking into account informal, community and cultural practices during all phases of data management (IFRC 2017, p. 017). These phases encompass the planning and design, the collection on site, the transmission, storage, Quality Assurance (QA) and Quality Control (QC) as well as subsequent analysis, presentation and dissemination of the outcomes (Fraisl et al. 2022).
All of these phases need to match the capacities of the organisation and of the contributing participants (IFRC 2017; E. Minkman 2015). Furthermore, all practices should focus on the end use and application of the data in supporting decision-making and follow the principle of data minimisation (EDPS 2023; IFRC 2017; E. Minkman 2015). In this stage, the planning of the data management procedures enters its detailed phase, is based on the established structure in stage 3 and results in precise methods, techniques, protocols and scripts. The methods should be simple, well-designed, peer-reviewed and standardised, while being fit for purpose (Fraisl et al. 2022; IFRC 2017; Silvertown 2009; Whitelaw et al. 2003). QA and QC procedures should ideally be integrated in every phase and follow the same high standards as the methods (Fraisl et al. 2022; Mackechnie et al. 2011; Sharpe and Cathy Conrad 2006; Silvertown 2009). Financial and human investments and resources need to be specified and parameters about the technical infrastructure such as architecture, storage, analysis, transmission and collection protocols and methods need to be defined (Fraisl et al. 2022; Sharpe and Cathy Conrad 2006). For data collection "the least intrusive and most cost-effective method available" is recommended (IFRC 2017, p. 27). The applied tools for data collection and transmission need to meet the available resources and technical abilities of the participant on site (IFRC 2017; E. Minkman 2015). Network coverage should be taken into account when implementing SMS or other remote devices but the (IFRC 2017, p. 26) notes, that "it is now increasingly rare to have absolutely no network access, but a bicycle messenger or another local communication system will also work". An automated, technical remote solution should be the preferred solution, but simple SMS and phone calls directly to the relevant manager or via traditional communication networks can also work, especially in cases where transmission speed is not of utmost importance (Gualazzini 2021; IFRC 2017). The requirements for data storage solutions include secure storage, good maintenance options and high up-times. The position of the servers and the ownership of the data can lead to disagreements with local stakeholders and should be well communicated (I2). Before the analysis of the data, robust QA and QC measures should ensure high quality of the collected data (Fraisl et al. 2022; Sharpe and Cathy Conrad 2006). The integration of other data sources for information triangulation is recommended. The analysis is the centrepiece of the data management and should follow the objectives of the overall project.

The outcomes should be made publicly available unless prevented by security or privacy concerns (ESCA (European Citizen Science Association) 2015; Sharpe and Cathy Conrad 2006). The type of presentation can show aggregated data, but should take into account the information needs of decision-makers. As with the issue of ownership of data, the procedures for sharing and presentation can also lead to disagreements and need to be managed sensitively. (I3)(IFRC 2017).

4.1.6 Stage 6: Evaluation and iterative improvements

Evaluation is an ongoing effort and should be considered at all phases of the project. The structure of the project should allow for evaluation procedures and subsequent implementation of the derived recommendations at all design stages and during operation (Fraisl et al. 2022; IFRC 2017). Success metrics as well as the response upon those need to be defined and agreed upon before the implementation of the project (Fraisl et al. 2022; Gualazzini 2021). The ninth principle of (ESCA (European Citizen Science Association) 2015) states, that "citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact". Underlying structures, practices and efforts can thus be configured and adapted into a more effective and efficient design and process. The integration of these assessments thus helps to progressively improve the use of data by decision-makers as well as the methods used (Fraisl et al. 2022).

4.2 Project requirements

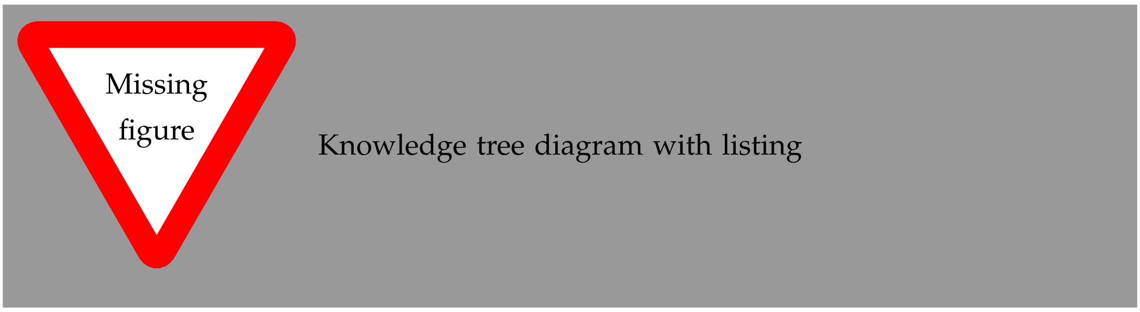
The stages of the roadmap outlined above give a good overview of what needs to be done and in what order. However, the process-oriented structure makes it difficult not to overlook important information, as there is no more detailed and grouped listing of this. This catalogue attempts to close this gap. The catalogue of project requirements presented here is divided into four groups of information that include (E. Minkman 2015)'s derived goals and sub-goals and follows the layer structure of the SLMC. For each goal, products along with their required activities have been defined in line with the above roadmap.
The first group **Knowledge Base**, see figure **??** contains everything that should be known for the project. It thereby serves as a knowledge base being filled throughout the above-mentioned stages. Activities are primarily about identification and information collection. The second group **Groundwork** contains everything on which the actual implementation of the project must be based on (see figure **??**). It includes the goals *Awareness Raising, Public Education and Policy Development*. The first two goals relate to products of information and sensitization measures for the target community, contributing volunteers and involved stakeholders. Activities focus on consulting with local elders and key stakeholders, and then informing and raising awareness among the whole community before the project starts. The third goal, *Policy Development* is about IWRM measures,

required products and their development. The activities aim to embed these into existing local management practices and procedures through identification and agreements with all affected and involved stakeholders. In order to facilitate this, new policy developments and adjustments may be required which overlap with the third group of **Innovations**, see figure **??**. This stage is important, as "there is no one-size-fits-all approach" (Fraisl et al. 2022, p. 2) and new developments of suitable and scientifically sound methods to meet specific challenges of the project tasks will be necessarily in every application and are summarised under the goal of *Method Improvements*. The last group **Management** contains all that needs to be done to successfully develop and implement a CS water source mapping and monitoring project (see figure **??**). The goal *Management Improvements* is further subdivided into products that are initially necessary once, recurrently and products that are required to embed the project in the context. The focus of the activities is on making decisions, developing procedures based on the **Groundwork** and **Knowledge Base** groups and implement developed methods from the **Innovations** group.
The order of the sections does not necessarily reflect the processing order but rather indicates dependencies whereas e.g. not everything need to be known in order to proceed with method development. The same applies to the order of products and activities (from top to bottom). However, to stay in this example, everything that, directly or indirectly, influences or is influenced by this certain method should be known. Therefore, stages 1 and 2 of the design roadmap should be completed before proceeding further with this catalogue in order to have a profound understanding of the local circumstances and their interconnectedness and interdependences.
The following sections briefly reason and describe the overall idea and content of each group. The activities are mostly already outlined in the above-described 6 stage roadmap, therefore the focus lies on the products of each goal.

4.2.1 The Knowledge Base: What needs to be known

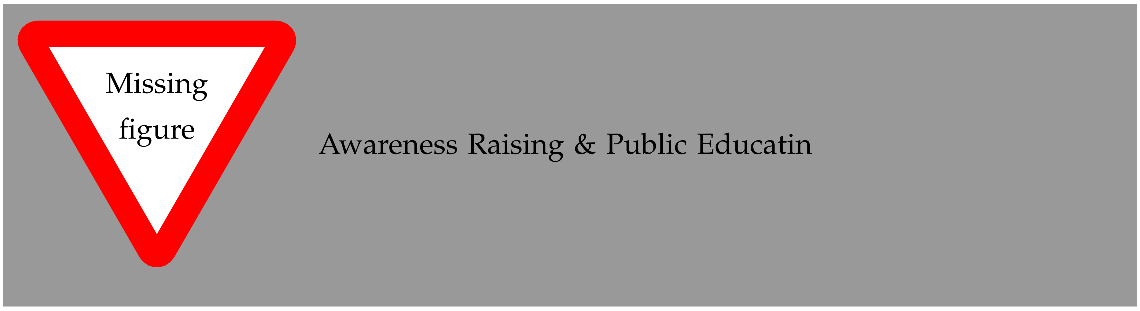
This Knowledge Base covers information and knowledge of all stages and is sub-divided into multiple products that each covers certain aspects of the project. The products (A), (B), (C) and (D) cover the baseline information of all stages. (A) includes information obtained in Stages 1 and 2 and, if this project is developed under an EAP, also the information from the overarching EAP assessment and feasibility study. (B) is the repository for all information related to the Citizen Science community and participant management, (C) covers all topics of data management and QC and QA integration and (D) relates to evaluation and improvement procedures. These products consciously resemble Stages 4, 5 and 6, and should be included right at the beginning of Stage 3. The structural basis for each of the subsequent stages is laid in Stage 3, and by bundling the information from the beginning, follow-up in the subsequent stages is simplified and streamlined.
Products (E) to (H) are more specific for the mapping and monitoring of water sources in an anticipatory context. (E) integrates all information for the first phase of mapping

and collection of key information on each water source including corresponding methods, while (F) includes all knowledge and methods on regular indicator monitoring. Together, this information enables actions on products (G) and (H). All potential AAs are first collected in product(G) and then narrowed down to those that can be triggered by thresholds related to water sources. The information about these thresholds along with triangulation data for the respective triggers is comprised in product (H).



4.2.2 The Groundwork: What needs to be built on

The Groundwork relates to everything, that needs to be in place, before the actual mapping and monitoring of the water sources starts. It is about giving the community all the information and knowledge to decide, manage and act on their own, only limited by the available physical and financial resources. Important is, that knowledge should not opposed on the communities but rather developed in close cooperation with the affected actors, their knowledge and practices. Therefore, the first product (A) of the goals *Awareness Raising & Public Educatin* (Fig. **??**) is about providing all the necessary background information to the community in order to allow them to make profound and informed decisions and contributions. Based on this, product (B) summarizes activities to address misunderstandings, reservations as well as expectations and concern handling. For this, the early involvement of community leaders or elders may be beneficial (I1). Product (C) refers to the sharing of information gathered in other phases with the community to keep their knowledge of prevailing and evolving circumstances up to date and to enable informed decision-making. In order to act on the information, product (D) summarizes the identification and transfer of information about water management and saving opportunities. Product (E) highlights the consideration, that even a single community is not homogeneous and that various groups with different interests exist within. Knowledge and measures to account for this are collected under this product.



Products A to E of goal *Policy Implementation*, figure **??**, represent (Day 2009)'s light community-based IWRM framework. The framework starts with the products (A) & (B) by identifying and assessing prevailing circumstances and requirements. From this, community water usage targets are derived and agreed upon in (C). Management guidelines, and priorisation plans are pre-defined and implemented in products (D) and (E). Product (F) goes beyond the framework and addresses measures related to data security and privacy.

4.2.3 The Innovations: What needs to be invented

New innovations may be required to successfully achieve the project objectives under the given conditions and in the given context. These developments are grouped separately because the development of appropriate, scientifically sound and context-aware methods can require a great deal of financial, material and human resources and should therefore receive specific consideration. In addition, the development of new methods is often a separate process that runs alongside the actual design and implementation efforts. However, there are now also many projects, guidelines and frameworks from which experience and best practices can be transferred. The developments can therefore also be an amalgamation of the old, tailored to new circumstances.

The products represent potential areas of such required innovations or adaptations. These can include areas of the initial and regular data collection, transmission, storage and analysis as well as, the determination of suitable thresholds, and their categorization for respective triggers.

4.2.4 The Management: What needs to be done

The group around management tasks is primarily concerned with the initial processes and responsibilities at the start of the project, tasks that need to be done regularly during operation, and specifications for solidly embedding the project in prevailing processes and practices. These tasks are about evaluating and processing identified and collected information to develop and make decisions about what elements, practices or structures to implement. The initial areas of concern (A) range from handling specific context related circumstances, to the development of training materials and evaluation procedures. Activities contributing to regular required products (B) are mostly concerned about providing training and supervision and implementing improvements derived from evaluations and feedback. Product (C) includes both initial and ongoing tasks, but is focused on embedding the project in the local context. It addresses the implementation of the *Groundwork* on community level and its integrations into prevailing local, regional and national structures, practices and stakeholder networks to make it relevant for decision-making.

4.3 Framework Application: Focus Somaliland

In this part, by applying the roadmap and project requirements described above, the fourth research objective of this thesis is tackled in order to ultimately achieve the overall aim of the research. Therefore, the results in this section are primarily geared towards the aim to identify and implement adequate water level threshold monitoring of the water source type of berkads in order to trigger respective AAs. The third stage is structured following the project requirement catalogue. The stages 4 to 6 refer their findings to the catalogue. However, because of their specific foci, they are not structured according to the catalogue. The above already displayed tree-diagrams can also additionally be found in the respective GitHub repository in Appendix **??**. This provides the reader with a simultaneous reference option, as the products and activities will only be mentioned by their abbreviations and not by their full name, to enhance readability.

4.3.1 Stage 1: Context and Problem Identification

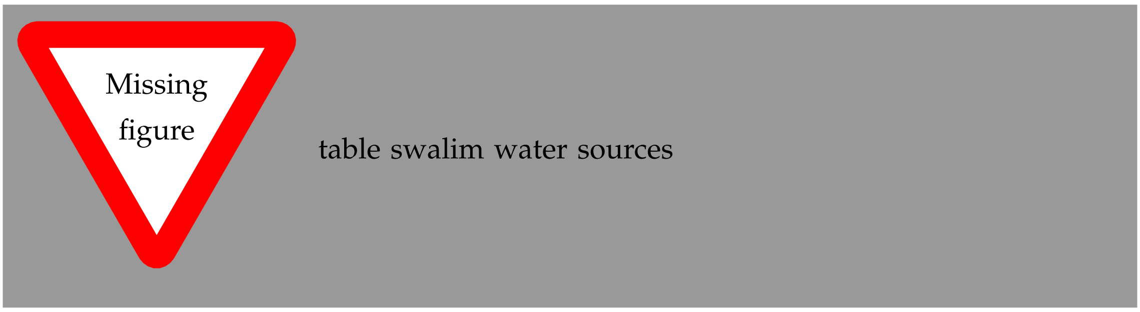
The brief water source data analysis along with given context, resource restrictions, stakeholders and comparable projects as well as problem and goal statements of the interviewees are covered in this first stage. It also builds on the preceding case study area section 2.5 in chapter 2.

The current drought and water scarcity situation in Somaliland has now lasted five years and has greatly impacted the water sector in Somaliland in terms of quantity and quality (I1). I1 describes the current crisis as *"huge and response activities are being overwhelmed by the need"* which will lead to *"commercialization and overpricing of fresh water"* further exacerbating the situation. This was underlined by I3 who describes the current water situation of the rural population as *"whatever source of water they can find is what they have"*. I3 further mentions, that the people sometimes *won't have enough water to wash their hands"* or for other necessary things and that *"they [then] don't think of what kind of water they can get, whether it's bad or something like that"* but only focus on having at least something to drink. Increased water shortage because of bad quality was also reported in the literature (see section 2.2.3). Water can potentially be contaminated at all stages of the water collection process, from the initial abstraction of water, through transport and storage, to the use of the water (I3). Water quality is difficult to assess on site, as the the colour is not a good indicator and other parameters can only be determined technically which required equipment and training (I1, I3). Furthermore, I3 confirms the reports in literature that contamination of water in berkads, through their shared use with animals, can happen even before water withdrawal. This depends very much on the construction method and how it is used. The rehabilitation as well as training how to adequately use a berkad are already activities of the SRCS (I3) and besides the water quality, the quantity also depends on the kind of construction and of withdrawal. According to I3, supply period can range from one month to half a year, so information on these parameters is crucial for estimating the potential duration of supply (I3).

Water monitoring and management is not seen as a problem in urban areas as there is an agency responsible for water supply but the problem is primarily located in rural and nomad areas, where 70 % of the people live, according to I3. (Somalia 2021), on the other hand, estimates an urban and semi-urban, sedentary population rate of 53 %.

The selection of beneficiaries for response activities of the SRCS are currently conducted on the basis of a preceding joint priority setting with the government. This prioritisation is based on *"assumed vulnerability per community based on Number of Internally Displayed Person (IDP) camps in the area, number of women headed families, predicted IPC classifications etc."* (I1.2). Anticipatory Actions (AAs) have not been implemented due to the *"already*

prevailing crisis" where the *"needs are [already] dire and the current SRCSs focus is on response mechanisms to address the already visible impacts of drought"* (I1.2). Thus, the overall *"end goal [of this project] will be to counter water shortages"* (I1) proactively but *"there has been any actions yet due to the fact that there is no water monitoring and trigger mechanism in place"* (I1). The monitoring was itself hampered by the fact that *"Berkads location data is currently missing"* (I1). This statement compares well with the experience of the current project team working on the EAP implementation and the assessment of available data sets (EAP project team, personal communication, 04.03.2022).
Table **??** shows all available data sets of water sources in Somaliland, provided by SWALIM.



The spatial distribution of the datasets across Somalia is relatively balanced, with focal points in the regions with many or larger settlements. Based on the SWALIM settlement data set, there are currently 2123 settlements in Somaliland. These settlement data are mostly from the years 2002 and 2006. The total number of water sources varies widely between and over time of the other data sets. The timeliness of the data also has a wide range, from relatively few pieces of data from 2019 in the 2020 dataset to data from the 1980s in the same dataset is much represented. The 2022 dataset misses information about timeliness altogether and the other datasets all have many blank entries as well. Furthermore, many water sources are labelled as 'abandoned' or 'non-functional', e.g. in the 2022 dataset those are 147 out of 685.
The data sets are fed by many sources and actors e.g. FAOSWALIM or other UN organisation, MoWR, NADFOR and other NGOs which constructed some water sources in some communities (I1). These actors, along with the community and their elders, local government representatives, SRCS and their volunteers and private berkad owners are also the potential stakeholders of the mapping and monitoring of berkads. Here, I1 notes, that besides the SRCS, the MoWR, NADFOR and the constructing NGOs are the most important stakeholders. The MoWR and NGOs have the technical expertise in construction, rehabilitation and monitoring and NADFOR has a comparable community level programme for monitoring *"livestock body condition, market prices as well as weather variables"* (I1).
Other comparable programmes exist from OCHA, BRCiS and the CBS programme run by the Ministry of Health, the SRCS and the NRC. While these projects may broadly be comparable in terms of focus on AAs, none of the Interviewees know of a project that conducts similar things to this works approach (I1, I2, I3). I2 also suggests that the projects are close enough to each other to pass on experiences and recommendations, e.g. from

the MoH to the MoWR, in order to overcome initial scepticism and reluctance.
Challenges, limitations and requirements are mentioned in areas of privately owned berkads, community expectation handling and the dissolution of misconceptions as well as potentially already overstretched SRCS staff and volunteers (I1). I1 mentioned, that private owners of berkads may prevent the volunteer from gaining access to their berkad which would result in less information on the one hand but also in tension in the community on the other. Giving information from the community to someone else may also generally require some explanation (I2). Furthermore, some *"information on past details per particular geographical areas"*(I1.2) can be difficult to access, as *"Somalis are highly mobile communities"* (I1.2). The monitoring could furthermore develop *"hugh expectations from the communities as there is the ongoing drought. Whenever there is monitoring of resources, communities believe this should be followed up by instant aid"* (I1).
Addressing some of the challenges mentioned above, the *"community elders should be engaged before the start of the mapping and monitoring as they will help dispel misconceptions about the project"* (I1) and the *"ministry of water resources should be in the loop during the entire project duration"* (I1). Nonetheless, the *"community and SRCS goals match as both focus on closing the knowledge [gap] currently existing"* (I1) in regard to the number, status of ownership, location and capacity of the berkads per community, district and regional level. This will *"inform decision-makers on the priority areas to focus on"* (I1). Therefore, I1 expects that this information from the site triangulated with weather forecasts can help to form robust triggers to take appropriate and informed Anticipatory Actions before critical water levels are reached.

4.3.2 Stage 2: Assess the feasibility of the Citizen Science approach.

In this stage, the practical capacities, and applicability and suitability of the CBM and MCS approach for community-based water monitoring were examined in this context. The SRCS has 249 paid employees, of which 30 work in the risk management and Anticipatory Action domain and an additional 1500 volunteers are "evenly spread" across the country (I1). I3 emphasises the *"good relations and good reputation"* that SRCS has within the communities, making them *"one of the most trusted organizations in the country"* which helps to do programs at community level. The 'feasibility study on Potential Use of FbF for SRCS' (**somaliredcrescentsocietyFeasibilityStudyPotential2022**) recognizes a *strong national organization* with a *strong volunteer base at community level* that *provides monitoring and hazard warning capacities*. Furthermore, *highly skilled and experienced management staff at coordination and Branch levels* is stated. Nonetheless, *minimal domestic resource mobilization* and a *lack of meteorological, geo-spatial analysis, data management and IT staff* has also been detected. This lack of resources and digital capacities was addressed in the CBS project by the NRC and their NYSS platform. Generally, CBS is *nothing new in itself and often used in health contexts* (I2). CBS in Somaliland started in Burao in 2018 with 75 community volunteers, as cholera had broken out in the same region in 2017 (I3). After the pilot was successful, CBS has since been extended to all regions but *SRCS only focusses on* *hot spot areas where they expect outbreaks to happen* (I3). This development took place over the course of a year with much feedback from the SRCS and NYSS is now *"very effective and very supportive"* (I3). The Ministry of Health (MoH) was and is *constantly in the loop to decide together what, how, when and who* and could gain good experiences with NYSS over the years (I2). By now, NYSS is well embedded in the local conditions and *"mobile teams [...] can be deployed immediately within hours so they can do the response"* (I3) in collaboration with other partners such as the *"government, MoH, WHO, and other sister RCRC organisations* (I3).

I2 mentions, that the monitoring of water sources *would fit well thematically, because it [low and poor water quality] is a health risk.* and that although it would require some adjustments and considerations, it would organically expand technical expertise and functionality as it is not *radically new*. Besides NYSS, being methodologically similar but different in thematic orientation, several other projects could be identified in literature, that are oriented towards the same topic but differ in their implementation and operation procedures (compare section 2.4.2). It can be deduced from this that CBM and MCS can in principle be applied to the thematic issue. Furthermore, (Fraisl et al. 2022) themselves describe approaches that focus on the "in situ monitoring" of water resources and at the same time benefit the respective participant as adequate for the use of a Citizen Science approach. SRCS does not pay their volunteers but provides training and covers travel expenses as incentives. Moreover, volunteers are generally well regarded and are selected by the community itself. Intrinsic motivation is therefore present (I2, I3).

(Fraisl et al. 2022) prerequisites are thus fulfilled, and the key objectives of the RCRC's CBS preliminary assessment as well as this works second objective can be answered positively. The task is applicable within a CS approach and the SRCS is an adequate partner with sufficient capacities and experiences to implement the mapping and monitoring approach. The project can thus be further developed in stage 3.

4.3.3 Stage 3: Designing the Project

This stage is grouped into the four project requirement groups and lays the structure for the coming stages. The overall project end goal to counter water shortages proactively is majorly hampered by missing information about the water source type berkad. Therefore, up-to-date information on water sources in Somaliland is needed. In particular, there is a lack of information on the important Berkad water sources (compare stage 4.3.1). Therefore, the focus of this project will be on gathering information about this specific water source type (I1). See chapter 2.5.2 for further information about this water source type. I1 also named and chronologically ordered the most important fields of action that need to be realised in order to achieve this goal:

1. Volunteer briefing and training
2. Community sensitization
3. Locating and gathering key information about berkads

4. Determination of the water level threshold
5. Determining respective Anticipatory Actions (own addition)
6. Monitoring of the water level
7. Triggering AAs based on pre-defined threshold

I1 highlights the importance of the actions 2, 3 and 7 as critical for the overall success of the project. For the design stage, I1 emphasises the determination of the threshold, Anticipatory Actions and respective trigger. As I1 draws his judgement from his work as the local program manager and coordinator, this project followed these priorities during the design process. This process is grouped by the project requirement catalogue in the following. The structure of each group follows the order of the products and respective activities, emphasis is given to the activities which contribute directly to the above mentioned priorities. To minimise repetition in the scope of this work, already covered areas are only referred to and not again outlined in detail.

The Assemblage: Knowledge Building

The majority of the activities of product (A) were already covered by previous stages and chapters. (A1) was extensively outlined in section 2.2. (A2) and (A3) were covered by stage 1 4.3.1, 4.3.2 and section 2.5. (A4) on the one hand will influence decision-making in the SRCS but further integration into e.g. governmental procedures could not be covered by this work. Activities A5 and A6 could also only be touched upon, but especially the topic of integration of local knowledge holds a lot of potential (see 2.2.4).
Product (B) could partly be covered by stage 2 4.3.2. Results so far suggest that the network and individual volunteers are adequately trained, motivated and managed for the monitoring task. This sets the framework for stage 4. In terms of adequate data management (C), feasible technical solutions could be identified from other projects and their practical applicability was demonstrated by the successful CBS program of the SRCS (C1). Further exploration in Stage 5 is thus possible. (D) current evaluation and improvement procedures could be identified and are further described in stage 6.
(E1) initially important information about each berkad is summarized in figure **??**. This compilation is based on section 2.5.2, and knowledge of I1, I2, and I3. The left, bold side are the information highlighted by the interviewees and summarizes the key information. The right side displays information, that may be nice to know for further analysis, but is not critical for this project.

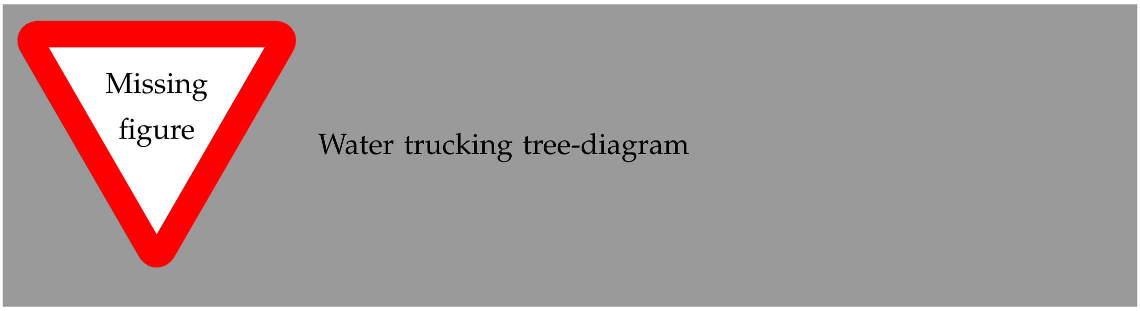
List of initially necessary berkad information

In terms of (E2), location, storage capacity and construction information need to be identified initially and might need to be updated when e.g. the berkad is rehabilitated. These information will be gathered by SRCS professionals and therefore does not need to be included in the regular monitoring routine. (E2) a report about the condition of the berkad may only be necessary once a year (I1.2) while the number of people and animals may need a weekly or monthly reporting interval, depending on the fluctuation strength (I1.2). This information should be kept comparatively up to date, as the high mobility of Somalis means that this number can change relatively regularly and has a great influence on the amount of water abstraction (I1.2).
(F1) the water level of the berkad was named as constantly changing indicator which should be monitored in a weekly interval (I1.2). The realisability and adequacy of this reporting frequency was also supported by I2 (F2). (F3) The data sets for the data triangulation are adopted from the overarching EAP and have not yet been determined at the time of writing.
Potential AAs that can be triggered in correspondence with a the surveyed information and certain water level threshold are listed below (G).

- Informing about water rationalisation and saving opportunities
- Information dissemination of climate and weather forecasts
- Distribution of drought-resistant crops
- Rehabilitation of berkads before the rainy season
- Compensate private berkad owners to access their water
- Timely distribution of cash to enable communities to buy and stock fresh water
- Timely distribution of water purification tablets
- Water trucking

Raising awareness and information dissemination need to be the foundation of this (see Groundwork **??**, I1.2). The distribution of drought-resistant crops and other agricultural related actions need to be coordinated with the Ministry of Agricultural Development (MoAD). The rehabilitation of berkads before the rainy season needs to be related to seasonal triggers as this actions will help to store available rain water and won't directly help in times of acute water shortages. I1.2 notes, that the involvement of private berkad owners *"could be limited as they are more concerned about their business models i.e selling of* *the water and preserving their berkads than being part of the overall response/Anticipatory action mechanism"*. Nevertheless, I1.2 sees potential in working with private berkad owners and suggests e.g. the rehabilitation of their berkads *"in return for their involvement in response and anticipatory action activities"* as viable AA. The distribution of cash is a widely applied AA in FbF project and can help in many cases. Distribution of water vouchers is an alternative to direct cash and has already been used successfully in Somaliland (see section 2.5.5). Water purification tables and information for waterborne disease prevention are already disseminated by SRCS volunteers together with hygiene and health promotion activities but could be better targeted by more timely and localised information (I3). Direct water transport is the last solution to mitigate water scarcity. The required lead time, tangible and intangible resources, information requirements and involved roles (G2 & G3) of these AAs are illustrated in figure **??**.

This list is not comprehensive and needs to be refined for each AA, which is illustrated in figure **??** for the AA *water trucking*.



Water trucking is a common measure to cope with acute water shortage in Somaliland. Information for water water trucking comes, thus far, from SRCS assessments, from the community themselves, government agencies, FSNAU or other NGOs (I3). This type of information transmission can be timely and may be incomplete. The water transport itself can take a long time and be relatively expensive due to the distance and high demand (I1, I3). It is financed by various stakeholders, including the community themselves and private donors (I3). Self-financed water trucking is especially common in the beginning of the initial phase of drought but if the people cannot afford to buy water any more and their livestock becomes weak or dies, *[...] this is the time they talk to the other NGOs or the government and say we need support [...]* (I3). Currently, the following prioritisation of water trucking by the regional and national stakeholders is primarily based on government decisions and focusses on the most vulnerable communities (I3). This decision-making

process could not be explained in more detail by (I3) other than it is a *joint effort by all stakeholders*. The SRCS does not truck water themselves.
(H1) potential water level thresholds were suggested by I1.

- Empty (no water at all)
- Critical (1 day of water supply remaining)
- Low (3 days of water supply remaining)
- Middle (5 days of water supply remaining)
- Hihg (full capacity)

I1 further specified the *Low* category to trigger the AA of *water trucking* (H2). These water levels either require the local knowledge about how long the water will last or require the analysis of the exact or categorized water level with the berkads capacity in the backend. The first option would outsource the triangulation of available resources and amount abstraction to the communities predictions. I1.2 notes, that *"these kinds of predictions are good as communities usually have their own control measures to ensure equitable distribution of water e.g. how many containers per family etc. The berkads are usually locked to ensure there is controlled access to the water stored."*. The second requires good information about the berkad itself and a feasible method to interpolate this with the regularly measured information. (Gualazzini 2021) however, proposed more seasonal focussed threshold levels for berkads (see chapter 2.5.5). (H3) the short-term thresholds may be feasible to short and fast AAs, whereas seasonal information may trigger AAs such as the rehabilitation of berkads and information campaigns.

The Groundwork: Laying the foundation

Volunteer briefing and training together with following sensitization of the community are the first two actions that lay the foundation for the implementation of this project (see 4.3.3, I1). (A1) major challenges could be identified in community expectation handling and the involvement of private berkad owners (I1, I2). I1 suggested, that the *"community elders should be engaged before the start of the mapping and monitoring as they will help dispel misconceptions"* (I1) and that the MoWR *"should be in the loop during the entire project duration"*. Awareness-raising activities and dissemination of information may include knowledge of water quality improvement techniques, water conservation strategies, early warnings and a detailed explanation of the reasons for reporting before the start of the project (I1, I2). It also needs to be *communicated, discussed and decided beforehand*, what happens in cases when thresholds are reached but no response is possible (I2). *Otherwise, it could fall back negatively on the SRCS and the Volunteer* (I2). Furthermore, I1.2 highlights the importance, to establish *"a robust feedback and complaints mechanism that ensures communities can easily relay their feedback.* right from the start. The development and implementation of product (A2), (B), (C), (D), and (E) must happen in close collaboration with local stakeholders and were thus out of scope of this work. Nonetheless, the work with the community should be fruitful as their goal to *"ascertain whether these water bodies are able to withstand the demand during drought periods"* overlap with the project goals (I1). The integration of the light IWRM framework developed by (Day 2009) was presented in section 2.4.2 and needs to be further discussed with local stakeholders.

The Innovations: Developments and Improvements

Besides the identification of a way to integrate IWRM practices into local procedures and structures, more technical solutions were also required to be developed or adapted. The actual outcome are part of stage 5. (A1) important primary information about the water source berkad could be identified by the method of expert interviews. (B1) and (C1) could be identified through interviews and literature analysis, where (B1) will either be a kind of categorised yardstick or a local estimation based on experience or a combination of both. However, a thorough assessment and subsequent adjustment of the practical suitability will only be possible in a pilot study. This is especially true for their evaluation (A2) and (B1). Several data management methods could be identified in literature, see section 2.4.2 and section 2.5.5 and applied in practice by other projects see sections 2.4.2 and 2.4.2. The desk-based evaluation (D1) has shown advantages and disadvantages for all, from simple to very dedicated implementations, thus allowing an informed decision in the coming chapter.

The Management: Mapping & Monitoring

This last group of the project requirement catalogue comprises activities for evaluation and decision-making on the pre-identified conditions in the preceding sections. Though, due to the overarching ongoing EAP development and no possibility to conduct studies on site, no decision or on site evaluation could be made in the context of this work. Nevertheless, a lot of information and good practice could be gathered and organised appropriately in the presented groups in the previous phases which will greatly facilitate future evaluation and decision-making, if read and considered.

4.3.4 Stage 4: Community Building

In the context of this project, the community volunteers of the SRCS are the contributing participants and their 'community' is the SRCS. The findings of this section contribute to the knowledge base primarily in areas (A4) to (A6) and (B) and form the basis for the participant and community related products and activities of the *Groundwork* and *Management* group. The volunteers are commonly not recruited by the SRCS in the common sense but rather chosen by the community (I3). Therefore, they are commonly not primarily selected on the basis of their education or skills, but on the basis of the community's own criteria (I3). The decision on who becomes a volunteer is generally made by the community committee and their elders (I2). I3 notes that volunteers generally have a *"good reputation in the community"*. *"After the selection, SRCS is doing a small assessment about e.g. reading and writing skills and then provide training to them"* (I3) according to their

tasks. Besides the social prestige, this training is also the primary extrinsic incentive to become a volunteer as the volunteers are not compensated otherwise (I2). Thus, volunteers need to be intrinsically motivated and *"willing to be a volunteer"* (I3). After the training, the volunteers are send back to their communities and start working there (I3). Volunteers are *mostly women as they stay in the community and do not travel as much as men* (I2). The work includes raising awareness about health and prevention hazards and informing about mitigation measures, as well as directly responding to them and, in the context of CBS, reporting (I3). Currently, in case of water shortage, volunteers educate people on how to prevent waterborne diseases by providing hygiene and health education and distributing water purification tablets. (I3).
Preliminary trainings, supervision and regular refreshers are seen, especially in the beginning, as important and as a great success factor by I2 and I3. In the CBS program, refreshers were conducted in a monthly interval but is no longer necessary in that frequency as the *volunteers know their business by now* (I2). Nonetheless, supervisors still validate and clarify reports, e.g. via phone or on-site visits. As already described in stage 4.3.2, SRCS spends a lot of time on community bond building and thus generally has a very good reputation with the communities (I2, I3). This greatly facilitates the information flow and response together with other stakeholders such as the MoH or NGOs (I2).

4.3.5 Stage 5: Data Management

Data management was first mentioned in the context of Mobile Crowdsensing in section 2.4.2 and more specifically in terms of Community-based Surveillance and NYSS in sections 2.4.2 and 2.5.5. In stage 4.3.2, the implementation of CBM and MCS was reasoned and the integration of the NYSS platform in the CBS program was further described.
This section contributes to the *Knowledge Base* in (C) but also influences the selection of AAs and trigger thresholds, as the data management capacities set the frame for the collection of respective indicators. It is less important for the products of the *Groundwork* but most developments of the *Innovations* group facilitate this stage. The actual implementation and its technical capacities will also strongly influence *Management* in regard to all data related developments and decisions.
I2 stated, that NYSS may be a good fit for the water level monitoring, when the primary orientation is on early warning and Anticipatory Action and not on general data collection. Discussions about the possibility to use NYSS are still ongoing at the time of writing. The potential integration of NYSS, together with its dedicated implementation, makes NYSS the preferred MCS platform for this project and it was therefore further explored in this stage. However, less automated and technical processes such as simple SMS or calls directly to the respective supervisor with manual data entry are also possible and common practice in many cbs projects (I2). The predecessor of NYSS itself was less automated and the evaluation was done with Microsoft Office (I2). These simpler

processes are, apart from the higher manual effort, mostly very comparable to the integration with NYSS in the areas of planning, implementation and evaluation, only less automatized.
I2 mentions in regard to the server location in Ireland and data ownership by the National Society and the location of the servers outside of Somaliland did not resonate well with the MoH and required a lot of communication. The progress made here could also be translated from the MoH to the MoWR.
The method of data collection via coded SMS should also work for monitoring water levels, whereas *one to three codes for regular monitoring should be alright but not more, as more codes make it more complicated and will narrow down the choice which Volunteer to take* (I2). Sending photos would possibly also work with this thematic focus, but would require smartphones and internet connection on the side of the collector. Though, I2 is *not supporting the distribution of smartphones for 'several reasons'*. However, less frequent transmissions with more codes would be possible through further aggregation. Therefore, the regular weekly water level monitoring as well as the seasonal major data collection would be facilitated by this method (I2). Small code explanations in local language and with images would need to be developed to give orientation and reference to the volunteer (I2).
The reports need to be validated and it *should be communicated, that reports will be checked by the supervisor in order to prevent false reports in hope of more water. If this happens frequently, a solution must be conceptualized* (I2). Despite all of these similarities of the approaches, I2 mentions, that the integration of the requirements of this project into NYSS will be work and that it needs to be discussed who does it and who pays for it.
The data collected within the NYSS platform, could recently be fused with other MoH data sets but that was *challenging and a lot of work* (I2). This shows, that while the automatic integration with other data, e.g. from the Ministry can be *laborious and complicated*(I2), it is possible. This would enable the (automatic) triangulation with "meteorological forecasts and local knowledge" (I1.2) already mentioned in previous chapters.

4.3.6 Stage 6: Evaluation

Evaluation is often referred to as an ongoing effort and the need to structurally integrate it at all stages was highlighted frequently in the above stages. From problem definition, through subsequent conceptualisation and design together with the community and stakeholders involved, to operation with regular training, supervision and feedback on each report, there is an opportunity for feedback and evaluation at every stage of the project (I2, I3). However, concrete measures of success still need to be defined with stakeholders before implementation. An evaluation of the implementation and operation could not yet be carried out, but there were already several iterations and improvements in the design phase, which could be implemented well with the present framework.
Evaluation practices are also already part of the organisational culture and procedures of the SRCS. This is particularly evident in the monthly meetings with the communities and

in the CBS implementation, which includes many feedback, evaluation and monitoring procedures. In addition, all interviewees mention the high investments of the SRCS in communication and feedback processes. I2 states, that *SRCS are no rookies. They know how to communicate as it is a big part of their culture.*

4.4 Summary Results + key lessons learned (?)

The results presented findings for the design of a community-based participatory water source monitoring approach, its improvement and subsequent application. The design roadmap adjusted and expanded (Fraisl et al. 2022) Six-Stage Framework to the prevailing conditions and context of the study area and project foci. The structure and respective thematic focus of the SSF have been retained, but expanded to include additional guidance, including best practices from the IFRC and the local BRCiS initiative. The first stage explores the overall context, the problem and derives initial approaches to solutions. The second stage assesses the feasibility of the Citizen Science approach in the given context. It goes into more detail, defines goals along with sub-goals and explores the actual possibility and capacities for a successful design, implementation and operation of a CS project. Only when this phase has been successfully completed, the requirements have been met and no *red flags* have been encountered, will the next phases be considered. Stage 3 *Designing the project* further specifies the previous findings and clearly focusses on the actual required products and activities to reach the goals. The overall structure is laid out by utilising the project requirement catalogue. Stages 4 to 6 go into more detail in terms of community building, data management, and evaluation and improvement practices respectively.

The mentioned project requirement catalog in stage 3 is presented in the second section of this chapter and is one result of this work. The catalogue was developed in addition to the above process oriented design roadmap in order to better structure and order the actual information to reduce cognitive overload. The catalogue is grouped into four groups namely *Knowledge Base*, *Groundwork*, *Innovations* and *Management*. Each of these groups incorporates one or more of the derived goals of Citizen Science by (E. Minkman 2015) and is design with the help of the Seven-layer model of collaboration. The defined products and activities are derived from the design roadmap, literature, guidelines, identified projects and conducted interviews. The *Knowledge Base* provides an overview of all topics for which information needs to be obtained and groups them loosely in order of their dependencies. The group *Groundwork* is concerned with the educational, social and political foundation in which the actual project should be embedded. *Innovations* covers all new developments that need to be made in order to adjust the framework to the local context and *Management* summarizes all other developments and decisions that are required in the previous groups.

The third section finally applies the design roadmap together with the project requirements catalogue on this projects' research question. The problem and context investigation (stage 1) along with the feasibility assessment (stage 2) defined a problem with a possible solution through a CS project. The project requirement catalogue could successfully be applied in the third stage to help structure and order the design process. This framework was subsequently deepened in the following stages. The design could continue until closer consolidation with local stakeholders and communities was required, which was not possible due to limited resources and time as well as the impracticability of on-site investigations due to the current situation. Higher-level decisions in EAP development that have not yet been made also limited this project in some aspects. Nevertheless, a good and orderly knowledge base, structure and conceptual basis for a first pilot study could be established.

Chapter 5

Discussion and Justification

This study aimed to design and test an approach for community-based participatory mapping and monitoring of water sources in a water-scarce and resource-limited setting in collaboration with the Somalia Red Crescent Society. The ultimate goal was to facilitate respective Anticipatory Actions in the context of Forecast based Financing and to improve water management and accessibility in underserved communities. To achieve this aim, four research objectives were formulated, including a comprehensive literature review to identify and evaluate principles for community-based participatory mapping and monitoring, assessing the feasibility of the approach in the given context, developing a replicable and adaptable framework based on the identified guidelines, and applying the framework to create a roadmap for implementation.

The literature and data analysis revealed the high complexity of the context and could determine gaps in the data situation on water sources as well as the project and framework landscape in regard to Citizen Science approaches in the given context for the implementation in a FbF project. However, the general feasibility of the approach for the project was suggested through further analysis. Building on this positive assessment, the identified frameworks and guidelines were adapted and expanded to ultimately lead to the development of a new replicable and adaptable framework for a community-based participatory water source mapping and monitoring in the context of Forecast based Financing. Its application on this specific case area resulted in a roadmap for the practical implementation of the project. This roadmap includes goals and sub-goals, required products and respective activities.

In this discussion chapter, the focus is on reflecting on the main findings and contributions of this study and discuss their implications for further developments and practical applications. In detail, each research objective is addressed in turn and its relevance to the research aim is discussed. Finally, limitations and challenges encountered during the research process are named and considered.

1. Objective + 1. RQ

5.1 Literature, Project and Data Analysis

Besides addressing the first objective, to *conduct a comprehensive review of existing literature and guidelines related to the design and implementation of Citizen Science programmes, and identify relevant work in regard to the research aim and overall case study context* the literature and CS project analysis could also create a sound foundation for the following study (see section 4.3.1). Breaking down the broad concepts of Water Security, Water Scarcity and Drought along with their indicators and indices to the local context highlighted that only relatively rough forecasts are available for Somaliland (see section 2.2.4). Currently, climate, weather and hazard forecasts for Somaliland are either based on international indices like SPI or on a scarce network of local weather gauging stations (see section 2.5.5). Besides their coarseness, these indices predict the climate or weather itself and not its impacts, making them unsuitable for Forecast based Financing (see section 2.3.1). For successful implementation of FbF, triggers and actions should be developed and directly linked (see section 2.3.2 and 2.5.5). This is often not feasible as local information about water sources is either missing completely, is incomplete or outdated (see section 4.3.1). This highlighted the need for new local impact indicators for the creation of which the CS approach was consulted. Several CBM, MCS, CBS, CBWM and other risk related CS frameworks and respective guidelines could be identified but none of them exactly matched the intended application (see section 2.4). While "there is no one-size-fits-all approach" (Fraisl et al. 2022, p. 2), the existing frameworks either focussed on different thematics, different contexts, had different participation levels, different goals or a combination of the above (see sections 2.4.2, 2.4.2 and 2.4.2). This is consistent with (Butte et al. 2022)'s and (Carrion et al. 2020)'s findings that existing frameworks guiding the development of water security data collection projects are often very specific and limited to certain factors, in many cases also not taking socio-economic factors into account. At the same time, frameworks like the on from (Butte et al. 2022; eu-citizen.science 2023; CitizenScience.gov 2023) and others were too broad, to be more than general guidelines. Therefore, no applicable framework existed for the implementation of a community-based participatory mapping and monitoring of water sources approach in a water-scarce and resource-limited setting. Especially not, with the focus on providing feasible information for triggering AAs in the context of an EAP and in collaboration with a RCRC National Society.Other networks like Building Resilient Communities in Somalia Consortium and the local branch of OCHA implemented their own early action approaches in Somaliland. However, on the one hand with different goals, and on the other hand with different methods (see sections 4.3.1 and 2.5.5). While BRCiS collects and interpolates qualitative local information, OCHA bases their early actions on the before mentioned large scale indicators. These approaches are either too slow or to coarse to address the aim of this research, but the concrete experiences from projects in the case study area are valuable to adapt and relate other information to the given context. The transfer of knowledge from other regions, projects and topics is necessary, as scientific literature about the case study area of Somaliland is generally scarce. In addition to these case

study related domains, there are further gaps in knowledge when in comes to the application of the FbF approach on the slow-onset hazard of drought. Generally, the concept of FbF is now well established in regard to fast-onset disasters, but the drought use case is relatively new (2020) and not yet well researched, which severely limits the amount of guidelines and frameworks available for this particular application (see section 2.3.1). Thus, each new project or study focussing on this hazard in the context of FbF has, at least in part, an exploratory character.
As any new project or study addressing this hazard within these concepts is thus 'automatically' exploratory in nature and no other suitable framework could be identified, the literature and project review suggested the need to develop a new framework to address the specifics of the case study (see section 2.4.1). However, before the new conceptualisation, the general feasibility had to be assessed first, leading to the second objective of this work.

2. Objective + 2. RQ

5.2 Feasibility Assessment

Since the feasibility had to be determined before this work could move on to address the other research objectives and questions, the second objective to *assess the feasibility of the Citizen Science approach in the given context by identifying potential challenges and opportunities for successful implementation, and to propose recommendations for addressing these challenges* was an interim result of the work. Based on the developed framework in section 4.1.2 the feasibility was already assessed in sections 4.3.1 and 4.3.2. This assessment combined and applied general, international guidance from many projects and studies with local experiences with the CBS program. It is believed that, even though no dedicated pilot study could be conducted, this combination and interpolation of experiences can reasonably suggest the feasibility of the CS concept for this application. However, this claim can ultimately only be verified or falsified by a pilot study on site. Furthermore, several challenges such as the embedding into local decision-making and processes, actual tailoring to local conditions and clarifying financial capacities could not further be investigated due to the limited amount of interviews with local stakeholders and ongoing developments of the superordinate project.
Due to the already conducted discussion in section 4.3.2 and challenges that cannot be investigated further in this context, the remaining part of this section focusses more on how, why and in what order this assessment was realised as it is believed that this holds more value to the reader than iterating over the discussion again.
Since, to the best of my knowledge, no work has been conducted with the combination of methods, goals and context of this work, there was no concrete existing guidance to assess the feasibility of this approach to achieve the research's aim in the first place. The lack of suitable frameworks for this project made it thus necessary to work on the development of the framework and its application step by step and not only chronologically, at

least to some extent. This was facilitated by the iterative working approach, which made it possible to first sketch out possible solutions and then deepen them when the conditions were met accordingly. This was also the case in addressing the second objective and the early conduction of the feasibility assessment is also recommended by multiple other guidelines (CitizenScience.gov 2023; García et al. 2021; IFRC 2017; IFRC, RCCC, and GRC 2023a; E. Minkman 2015).

The Six-Stage Framework and Seven-layer model of collaboration were adopted at an early stage of the work to have a general direction for the development. To conduct the assessment, the third research objective had to be somewhat anticipated in order to provide an initial framework for the structured feasibility assessment. This framework, now conceptually integrated in the second stage of the design roadmap (see section 4.1.2) was in the beginning primarily a combination of the SSF's second stage and the feasibility assessment of the CBS of the IFRC. The final feasibility assessment took place on the current basis, which was further underpinned with some additional guidelines, best practices and knowledge of the interviewees over the course of multiple iterations.

When designing a framework for or directly assessing the feasibility of CS, it becomes clear that *feasibility* depends on a variety of factors, but also that there are no clear rules that must be followed. Each CS project is somewhat special and the flexible concept also allows for several adaptations (see section 2.4). Therefore, the feasibility is not assessed by a specific set of rules, but rather how well it relates to general principles and factors of success. This makes sense in the way, that what specifically works in e.g. (E. Minkman 2015)'s approach in the Netherlands may not be feasible in Somaliland, e.g. the use of smartphone sensors as the rural population in Somaliland has few smartphones and internet coverage is poor. Assessing challenges and opportunities is thus a highly specific and local task and depends on many factors.

Nonetheless, the ECSA along with many other associations and studies developed CS principles and characteristics that support the successful design, implementation and operation of a CS project. Furthermore, a CBS project was already successfully implemented and in operation for several years within the context and the SRCS but focused on a different topic. This, again highlights the thorough analysis of local comparable projects, mentioned in stage 1, section 4.1.1. The actual feasibility assessment therefore focussed primarily on the differences between the CBS and the potential water source mapping and monitoring project.

3. Objective + 3. RQ

5.3 A Replicable and Adaptable Framework

Having established the feasibility of the CS approach, the third objective to *develop a replicable and adaptable framework for community-based participatory water source mapping and* *monitoring in the context of Forecast based Financing, based on the principles and recommendations identified in objectives 1 and 2* could be pursued. There are now a high number and wide variety of guidelines, CS associations, initiatives and projects to choose from, that the question of the necessity to add just another one to the list suggests itself. The literature analysis suggested that, above all, the high variety is explained and reflected in the high diversity of the CS approach of e.g. methodology, temporal and spatial scale, goals, context, level of participation and overall goal (see section 2.4). (Fraisl et al. 2022; Weston and Cathy Conrad 2015) and (Zheng et al. 2018) all summarise a wide variety of these guidelines and (García et al. 2021) even created a *Guide to Citizen Science Guidelines*. Nonetheless, none of these met the needs of this work, which prompted the development of a new framework. That goes along with the recommendations, of (García et al. 2021), that the development and thus transfer of experience in guidelines is the currently the best practice in the field when new, previously unrealised combinations of the thematic diversity listed above are approached and realised (García et al. 2021). This highlights the need, that frameworks need to be focussed on a specific topic, region and environment in order to give meaningful advice and not only generic information that is too coarse to be of great use.

The decision to build on (Fraisl et al. 2022)'s Six-Stage Framework was primarily driven by its timeliness, comprehensiveness and focus on environmental issues as it was clear, that a more social and local component can be integrated from the SRCS's experiences with CBS. The usefulness of the interpolation of these two approaches was particularly evident in the consideration of personal data. While observing natural phenomena at the level of data collection did not raise too many privacy concerns for (Fraisl et al. 2022), this was almost the opposite for CBS (IFRC 2017). Applying these contrasting perspectives to the issue of water sources was thus able to address both the physical and social components well by considering trade-offs between the two 'extremes'. This claim was further supported over the course of this work, when the iterative integration of other guidelines from several divergent foci into the existing framework could be implemented smoothly and only minor revisions had to be made. (McGowan et al. 2022) also found that the success factors of CBS are closely linked to the general principles of participatory community engagement and could therefore be transferred to other participatory surveillance preparedness activities. As the individual stages are outlined and described in detail in section 4.1 and all identified relatable guidance is included into the design roadmap, no further discussion of the individual stages will be undertaken. Nonetheless, this processual SSF has some short-comings which will mostly be addressed in the discussion of its actual application (section **??**) and following limitation section **??** of this entire work.

However, a couple of shortcomings became apparent right at the beginning of the application in the third phase. It was increasingly difficult to keep an overview of the actual project requirements and their interdependencies in terms of subject matter and temporal constraints (see section 4.2 and 4.2.1). Furthermore, CBS, CBWM and other approaches have strongly emphasised the importance of embedding the project into prevailing social and decision-making conditions and procedures, which was under-represented in

the SSF (see section 4.2.2). The Interviewees also highlighted, the time (over a year) and resource requirements, which they needed for the development and adaptation of methods and techniques to start with the CBS project in Somaliland (I2, I3). This goes along with (García et al. 2021)'s findings, that some adjustments and tailoring always need to be done when implementing a new project (see section 4.2.3). Together with the emerging need to structure smaller developments and create an overview of decision dependencies, a fourth area of management became apparent that needed to be addressed >(see section 4.2.4). These reasons provided the ground for the new development of the Project Requirements Catalogue to expand the SSF from the third phase onwards. Since the first and second stages are primarily exploratory in nature, it is believed that the PRC should not be integrated in these stages, as it could limit the exploration to the given categories. Should something be overlooked, completions are still possible at the beginning of the third phase.
The conceptualisation and structure of the PRC with the Seven-layer model of collaboration, guided by the derived goals by (E. Minkman 2015) further supports the structuring and elaboration of the dependency. Emphasis is given to the top three layers, the *Goal-, Products-, and Activities-Layer.*, firstly due to time and information constraints and secondly as practical applicable *methods, techniques, tools and scripts* need to be highly adjusted to the local context (see section 3.2.2). Both are main limitations of this work and will further be discussed in the last section of this chapter. Nonetheless, the limitation of this work may not be true for subsequent work, which can then benefit from the deeper and more detailed structural possibilities of the SLMC. Despite the fact that the thematic focus of the SLMC is not on CS, the overall design pattern could be adopted well. The successful preservation of design patterns to other fields is also supported by (Diggelen and Overdijk 2009)'s findings. Thus, although the work has a sound methodological basis, it is primarily based on the perspective of a process- and requirements-oriented understanding and reasoning of the design phase. Other perspectives such as resource, behavioural network or stakeholder networks, cultural norms and values, as well as the communication network perspective may play a role in certain aspects, but are of secondary importance in this work. Engaging these other perspectives more in depth could yield further important insights by encouraging a more holistic view of the design.

4. Objective + 4. RQ

5.4 Application

The fourth research objective to *apply the adapted and developed framework to establish a roadmap for the implementation of a water source mapping and monitoring approach to trigger appropriate anticipatory actions to address water shortages* has already been partially addressed under the first two objectives. Stage 1 was primarily addressed by the first research objective which explored much of the underlying concepts, context, prevailing problems and also carved out potential solutions. Stage 2, the feasibility assessment, was addressed

with the second research objective. Therefore, this section concentrates on the stages three to six.
In stage 3, the subdivision into the PRC was helpful to reduce cognitive overload and highlight chronological and thematic (inter-) dependencies. In terms of knowledge, the PRC helped to structure the identified information from stages 1 and 2, which additionally helped to make knowledge gaps, such as e.g. missing detailed knowledge about local decision-making procedures, obvious. As it is was not feasible to gather these information in the scope of this work, it was therefore simplified to concentrate on those areas, that could be tackled. For example, it became clear that the initial mapping, which includes gathering other key information about the berkad, cannot be done by local volunteers as the knowledge and technical equipment requirements are too high for most. Thus the initial mapping needs to be conducted by the SRCS professionals who are already experienced and don't need further guidance for the process. Nonetheless, gathering the information that is initially required was feasible in the context of the work and thus focussed on. The knowledge gathered was thus more broad than deep and in most cases requires further investigation, especially in relation to local conditions. For example, in the case of the AA of water trucking, see figure **??** in section 4.3.3, requirements could be listed, but their actual specification is only possible on the ground with local stakeholders.
Close and early cooperation with other local actors in the area of embedding the project in conceptual water management practice was also suggested as important by the interviewees (see section 4.3.3). This compares well with common recommendations for CS projects (see section 2.4). To facilitate this, a light IWRM framework which was also already tested in other local circumstances could be identified in (Day 2009)'s adaptation. Yet, the same limitations apply here, as the actual feasibility can only assessed on the ground. Nonetheless, the willingness and experience of local managers to implement those concepts could be identified, which suggests at least a good initial situation for the successful embedding of the project into local management practices. The great importance of deep local embedding is also highlighted by (Gualazzini 2021) because even if the information gathered is good and timely, it still needs to be incorporated in decision-making and acted upon.
Besides the conceptual groundwork directly on site, innovations for the determination and collection of water level thresholds are required. The gathered information suggest, that there are two potential ways to assess the water level (see section 4.3.3). The technical measuring and transmission of the actual water height would require the knowledge about the exact capacity and size of the berkad to assess the water level. Although this method would provide a more objective measurement, local knowledge of the potential duration of water supply was also found to be good with a Berkad (see section 4.3.3). Both approaches do not contradict each other and could also be used together. This would also allow a good basis over time for evaluating the quality of the assessment of local which could what could then improve local water management. In addition to

the quantity of water, its quality was also considered very important, but no locally feasible approach to assessing quality could be identified. This supports the importance of providing a sound knowledge foundation about contamination prevention and water management practices to the community. This is also supported by several other studies (Daniel et al. 2020; Huang et al. 2020; Tariq et al. 2021; WMO 2013). Research in this field is still ongoing (Tariq et al. 2021) and (Delaire et al. 2017) cost estimations suggest, that even with current equipment, costs are minimal in relation to achieving the SDG 6.1 of safe water for all.

While no management decision or concrete developments could be made in the scope of this work, the results suggest some additional considerations. In the case of deciding for a specific water source monitoring strategy, all accessible water sources in a community should be monitored, as the largest, e.g. a ballay, is not necessarily the one that can withstand a period of drought the longest. Physical as well as social access factors need to be considered in terms of actual water withdrawal and monitoring when deciding on the actual monitoring routine see section 4.3.3. Furthermore, the results support the feasibility and usefulness of a staggered trigger as proposed by (RCRC 2020) for triggering on water level thresholds as both, a seasonal and a short-term assessment are possible. In terms of AAs, the results mostly supported the feasibility of water trucking and cash transfer AAs (see section 2.5.5 and 4.3.3), which compares well with (Gettliffe 2021) findings. Yet, when comparing this finding with the statements of the interviewees from section 4.3.1 that water is often over prized in times of scarcity and with the statement of (OCHA 2020) that markets need to be operational to permit this handling of the demand, distributions of cash or water vouchers may not always be feasible as AA. Besides the social factors (Birch 2008) further highlights that impact on natural ecosystems through water availability for animals need to be considered when addressing water shortages. The community building aspect in stage 4 was mainly focussed on assessing the capacities of the SRCS. The findings suggested good capacities and high experiences in the area of community engagement as well as volunteer training and supervision (see section 4.3.4 and 4.3.2). This was to be expected, as the SRCS already implemented a comparable project and was also found to be performing well within the framework of the overarching FbF project. Findings of Stage 5 *Data management* support the technical practicability of the project. The solution of the implemented CBS project with the NYSS platform was found to be very dedicated and technically adaptable to the new requirements. Currently, discussions about the adaptation are ongoing on management level. In addition to this very automated and already well-rehearsed system, however, several other potential systems could be identified which, although not quite as advanced or tailored, would also suffice for the application for the time being (see section 4.3.5and 2.4.2).

A major concern of data collected by CS is their quality and accuracy. This is well addressed in the current CBS program with initial and refresher trainings, close supervision and further verifications when necessary. Together with the built-in automatic checks in NYSS, measures of QC and QA are well considered. It is expected that these mechanisms can be translated to the new project largely addressing quality concerns right from the

start. Constructed validity needs to be addressed by further data triangulation, as the simple measurement of the water level itself does not proof, that the underlying reason for low water levels is indeed a drought but could also be reasoned by social factors (see section 2.2.2). Evaluation practices are integrated in every stage but due to no actual implementation and operation, evaluation could not be conducted. Nonetheless, the design process, due to its iterative processes underwent several evaluations and piecemeal improvements itself suggesting good adaptability and upgradeability.
The overall application of the developed framework worked well and the combination of the SSF together with the PRC based on the SLMC could provide good guidance while also remaining flexible to incorporate new, unexpected findings. Yet, the entire power of the SLMC could not be exploited as the coming layers were too detailed and most of those need to be determined in closer collaboration with the team and the local stakeholders. Nonetheless, based on the positive experiences with the first three stages, it is believed that the following layers will also prove fruitful to potential future developments.
The application also supports the findings of (García et al. 2021) and (C. T. Conrad and Daoust 2008) that a framework should be used but also highlights the need to adapt this framework the actual projects conditions and goal. Furthermore, the work suggests that a respective implementation of a Citizen Science project is not only theoretically feasible but practically implementable. While an end to end establishment of an implementation roadmap was not feasible in the context of this work due to several information, resource and time constraints, a sound foundation could be laid for further practical implementation in the scope of a pilot study. Yet, important questions need to be answered on management level and not all indicators are in favour of a practical application. For example, the RCRC is generally not recommending its National Societies to implement their own data gathering strategies as this would, under normal circumstances over-burden and exceed costs (RCRC 2020). Therefore, (RCRC 2020) generally recommends to found the triggers and information on already gathered information by other stakeholders or international organisations. As suggested by the results, this is not feasible in this context. Furthermore, the analysis of the CBS approach and other projects together with the feasibility assessment and conducted application of this work suggest that CS can be reasonable and cost-effective approach to gather relevant information. This is also supported by (Aceves-Bueno et al. 2015) and (E. Minkman 2015) findings. Timely and accurate data can support the appropriate Anticipatory Actions to be tailored, making mitigation and response potentially more streamlined, efficient and effective.

5.5 Limitations

In any research project, limitations are an important aspect to consider and some were already addressed in the above discussion. Yet, there are further limitations that need to be acknowledged. The literature review did not follow a strict formal structure and that comparable projects may have been overlooked, although unlikely, cannot be ruled out.

Nonetheless, this exploratory approach also allowed for the discovery of many, formerly unknown aspects and contributed many insights to the study. The subsequent in depth literature review, although not formal, was detailed and extended and was able to identify and close some gaps. However, the generally sparse literature on Somaliland limited the desk-based collection of information about local conditions. Furthermore, this work has also not addressed the integration or application of local and/or indigenous knowledge or the further use of VGI, to the extent that this would have been possible in principle. Although both areas are very interesting, this was either not the focus of this work or, the case of available water source datasets and VGI an in-depth analysis had been deemed unsuitable due to the poor quality identified early on. Nevertheless, insights could be gained from the data using more refined methods in future work. On the theoretical level of the contextual basis, the concepts mentioned, such as water security, drought or Citizen Science, are extremely complex and highly debated topics. Discussing them in detail would have exceeded the scope of this thesis, which is why focal points were set according to the priority of this work.
The inclusive nature of the exploratory approach, was thus tried to be addressed by information triangulation from other studies but it made for a generally more consensual work and fewer contradictory findings. This, together with the inclusion of most relatable studies and projects into the framework itself, also made for a relatively homogeneous discussion due to the lack of contradictory findings. It is expected that this comparison with other work will be possible in the future as more CS projects are carried out in a similar context and with similar objectives.
The critique of the case study research type, its challenge to execute, significant documentation efforts and complex nature also had certain shares in this work. Nevertheless, its strength of being rich, detailed and contextual also contributed positively. The generalisability of the understanding gained through actual application can be considered low, but the applicability of the framework developed can be expected to be transferable to other comparable contexts.
An attempt was made to improve internal validity through the iterative design, reciprocal reviews and triangulation of multiple sources of information, but despite great efforts, it is hardly possible to establish causal relationships in such a complex environment. Constructed validity of the framework is believed to be reasonable due the extensive triangulation of resources but can only be tested in a practical examination. The importance of data triangulation was also noted and integrated in the actual application. Interviews always add a human factor which can complicate repeatability but clear procedures and documentation were established to account for this as best as possible. The expert and snowball sampling strategy itself worked well, but was severely limited by other factors. The interviews always had to be arranged and signed off by senior managers, and the already tense situation with ongoing response activities and parallel FbF development in Somaliland made the availability of interviewees even scarcer. This resulted in a relatively low sample of interviewees, limiting the otherwise strength of a case study

to incorporate a multitude of perspectives on one area of interest. Here, interviews especially with representatives of NADFOR, the MoWR and MoH as well as BRCiS and OCHA mights have been fruitful. The conversion of one interview into a questionnaire hindered direct clarification and follow-up questions in the interview, but this could be compensated for by a second questionnaire. Since a lot of information could be drawn from the answers and the interview could not have taken place otherwise, this can ultimately be seen as a good compromise.
Overall, the study was conducted under difficult conditions in a case study area known for its complex and difficult environment. The generally limited time and resources available in the context of a Master's thesis further constrained the study and the focus on just the development of the framework might have been beneficial. Nevertheless, it is believed that the study conducted was ultimately able to provide a good theoretical and structural basis for a potential practical implementation of this approach. Furthermore, this study contributes to the general ongoing discourse of Citizen Science-projects by adding a work from a currently underrepresented region. It is to be expected that in the further process of this discourse many of the limitations mentioned here can be addressed and overcome.

Chapter 6

Conclusion

6.1 Conclusion

This chapter concludes the study by summarising the main research findings in relation to the research questions and aim and discussing their value and contribution. It also illustrates the limitations of the study and suggests possibilities for future research.
This study has investigated the intersection of Forecast based Financing policies and techniques, Citizen Science approaches and methods, and water management structures and procedures in Somaliland. This was attempted by *adapting and applying an approach for community-based participatory mapping and monitoring of water sources in a water-scarce and resource-limited setting in collaboration with a national non-governmental organization to facilitate respective Anticipatory Actions in the context of Forecast based Financing, with the goal of improving water management and availability to address water shortages*. Utilizing a mixed-methods approach that combined literature analysis and expert consultation, a tailored framework could be developed and an implementation roadmap created. The results show that integrating the concepts of Forecast based Financing and Citizen Science for monitoring and Anticipatory Actions based on water source levels in resource-scarce settings into one framework is theoretically possible. In the case of Somaliland, the practical feasibility of this integrated framework can also be assumed to be feasible based on the results.
Fundamentally, this work further diversified the literature on Citizen Science projects by contributing a case study in regions other than North America and Europe. The development of the adaptable and replicable framework in this context may allow other work with similar aims and conditions to have a closer start of reference for designing their own project. Specifically in this context, the thesis laid a starting point for the implementation of a practical pilot study by the Somalia Red Crescent Society. Therefore, perhaps contributing to better data regarding water sources and ultimately leading to the implementation of Anticipatory Actions.
This study was primarily constrained by a modest number of interviewees, no opportunity for on site work and general time constraints. Therefore, the work remained at the conceptual stage and could not be evaluated against a practical application. Other evaluation options, such as comparison with other projects, were not feasible due to the

novelty of the project and the consequent lack of similar ones. In addition, no concrete technical approaches and possibilities for data triangulation could be formulated because decisions at management level had not yet been finalised.

Future research can directly continue where this work left of by implementing an on site pilot study, continue to dig deeper into one of the many questions that have arisen or focus on overcoming the current limitations. A pilot study could potentially address all primary constraints of this work and continue to adapt, implement and evaluate it locally. However, before a case study may be conducted, there are several other questions worth asking. In regard to local embeddedness in the community, the heterogeneity, gender inequalities and the involvement of the elders are exciting fields. Also, what lies at the intersection of two-way communication and integration in terms of local and indigenous knowledge, ways and benefits of the distribution of weather and climate forecast information and warnings are also highly interesting areas. The investigation and evaluation of solutions for awareness raising, public education, volunteer engagements, policy development, decision-making, method improvements and data quality may be further paths to explore.

The limitations of low external and internal validity and the question of whether the framework can be applied to other contexts be addressed by further case studies in similar contexts or the inclusion of other methods such as upscaled surveys. The further investigation of the link between the water level proxy, vulnerability and impact may add further value to argument of constructed validity. In addition, inter-project comparisons as well as comparisons with other methods, e.g. (remote-) sensor networks could be investigated.

In conclusion, the situation of water in Somaliland could be identified as a highly complex and challenging environment. The combination of Forecast based Financing and Citizen Science could be identified as potentially fruitful for monitoring water source levels. A further, especially practical, investigation into the issue and linking it to preventive measures may contain great value. In addition, proof-of-concept, -value and -use may be demonstrated by going the last research mile.

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