HEIDELBERG UNIVERSITY

MASTER THESIS

Super duper fancy title. DONT FORGET TO CHANGE THIS!

Author:
Bosse SOTTMANN

Supervisor:
apl. Prof. Dr. Sven LAUTENBACH

Examiner:
Prof. Dr. Alexander ZIPF

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

in the

Institute of Geography
Faculty of Chemistry and Earth Sciences

April 14, 2023

Declaration of Authorship

I, Bosse SOTTMANN, declare that this thesis titled, “Super duper fancy title. DONT FORGET TO CHANGE THIS!” and the work presented in it are my own. I confirm that:

- This work was done wholly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date:

“”Can’t A Guy Make One Mistake?””

Baloo, The Jungle Book

Abstract

Super duper fancy title. DONT FORGET TO CHANGE THIS!

by Bosse SOTTMANN

Ensuring water security is considered as one of the major challenges of the twenty-first century. The trend of increasing demand and diminishing supplies is putting pressure on the availability of water worldwide. Particularly in the Horn of Africa, drought impacts determine the life of millions of people. Somaliland is in the midst of a years-long drought and water sources become more important than ever. Yet, information particularly about the most important water source type of berkads is incomplete and outdated.

The poor data availability severely hinders Disaster Risk Reduction activities especially in regard to Forecast based Financing. Triggered by predicted disaster impacts, Anticipatory Actions attempt to counteract impacts before the disaster occurs, rather than responding to post-disaster impacts. However, drought is a relatively novel application focus for this approach and highly dependent on good and timely information.
Citizen Science has successfully been applied to provide data for acting on environmental issues primarily in North America and Europe. Furthermore, Community-based Monitoring together with Mobile Crowdsensing currently provide the conceptual backbone to the health related Community-based Surveillance project by the Somalia Red Crescent Society. Building on the combination of these concepts, the aim of this study is to develop and apply a new approach for community-based participatory mapping and monitoring of water sources in this water-scarce and resource-limited setting in collaboration with the SRCS to facilitate respective AAs in the context of FbF, with the ultimate goal of improving water management and information availability to address water shortages.

The work is embedded in a primarily inductive design of an exploratory, iterative case study, and guided by a mixed-methods approach combining literature analysis and expert consultations. The results indicate that it is conceptually possible to integrate the concepts of FbF and CS for monitoring water sources in resource scarce settings to eventually trigger AAs within one framework. Moreover, in the case of Somaliland, it can also reasonably be assumed that the practical feasibility of this integrated framework is given. Future work on this basis will be able to integrate and evaluate local information by means of a pilot study, thereby overcoming the main limitations of resource, time and information constraints.

Acknowledgements

I would like to express my deep gratitude to Prof. Dr. Alexander ZIPFfor providing me with the opportunity to write my thesis in the frame of the GIScience at the University Heidelberg.
To apl. Prof. Dr. Sven LAUTENBACHand *Dr. Michael Auer* for their time, continuous guidance and great humour during our numerous meetings.
To *Melanie Eckle-Elze* and the *HeiGIT Disaster Team* for their willingness to involve me in the project, practical help and encouraging support.

I would also like to express my gratitude to all interviewees for their valuable time and shared perspectives and experiences. Their contribution has been indispensable to the success of this study.

Special thanks to my *family*, *flatmates* and *friends* for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without you. Thank you.

Contents

List of Figures

List of Tables

Chapter 1

Theoretical Background

1.1 Introduction

This chapter provides an overview of the theoretical background of this thesis, including key concepts, theories and literature in which this thesis is embedded. The chapter starts with a discussion of broad concepts such as *water security*, *water scarcity*, and *drought*, along with their characteristics and differences in section 1.2.Building on this foundation, the section 1.2.4 introduces the approach to measure and monitor these wide concepts through indicators and indices together with the ideas of risk, vulnerability, and impact. Extending the 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 the Early Action Protocol structure, forecast based decision-making, setting strict thresholds for when to act, and finally what to do when thresholds are exceeded.
Drawing on the realisation that the current data basis for predictions is too coarse for precise measures, another broad field *Citizen Science (CS)* is introduced in section 1.4. Following this, sub-concepts of Community-based monitoring (CBM) and Mobile Crowdsensing (MCS) are further introduced and with Community-based Surveillance (CBS) and Community-based Water Monitoring (CBWM) concise examples for successful implementation in local context and thematic transferability of the approach are given, respectively.
Section 1.5 anchors the concepts mentioned so far in the local context and addresses local specifics. The geographical and climatic conditions, the historical and current economic and socio-cultural context, and ongoing implementation efforts for anticipatory measures further describe the case study area of Somaliland. The chapter concludes with a summary of the key take aways and establishes a link between the findings and the further thesis.

1.2 Fundamental Concepts

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 (Sadoff et al., 2020). 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" (Grey & Sadoff, 2007, p. 1).
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 (Mishra et al., 2021; Van Beek & Arriens, 2014). 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.

1.2.1 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 1.1 (UNDRR, 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; UNDRR, 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; UNDRR, 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, the (dictionary of the English language, 2022) defines drought as "a long period of abnormally low rainfall, especially one that adversely affects growing or living conditions". Palmer (1965) defines drought as "a prolonged and abnormal moisture deficiency" (p.2) and Van Loon et al. (2016) defines droughts simply as "temporary lack of water compared to normal conditions" (p.3637).
Other drought definitions emphasize its natural and 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, p. 3). 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; UNDRR, 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 & Glantz,

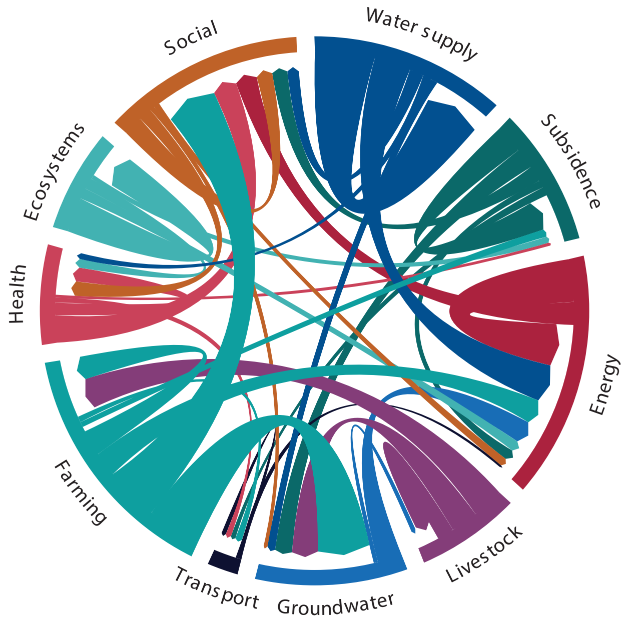

FIGURE 1.1: Schematic representation of potential interconnections among different sectors affected by droughts. Note: Each sector is represented by a fragment on the outer part of the circular layout. Arcs are drawn between each sector with the size of the arc being proportional to the importance of the trade-off. Source: (UNDRR, 2021, p. 47)

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 (Balint et al., 2013; NDMC, 2023b; Wilhite & 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 (UNDRR, 2021; Wilhite & 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.

The *meteorological drought* is usually characterized by the duration and the degree of dryness in comparison to the normal average and tries to conceptually understand how weather patterns can impact water availability. Definitions in this category are specific for a region's atmospheric conditions. That is to say that regions with a year-round precipitation regime such as the tropical rainforest need different definitions and thresholds than e.g. climates characterized by seasonal rainfall patterns (NDMC, 2023a). 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 (Balti et al., 2020; NDMC, 2023a).

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 (Balti et al., 2020; NDMC, 2023a; Wilhite & Glantz, 1985).

The *socio-economic 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 economy. It is therefore sometimes also interchangeably used with drought impact. Operational categorization involves using socio-economic indicators such as unemployment rates and food prices to assess the severity and duration of the drought (NDMC, 2023a; Wilhite & Glantz, 1985).

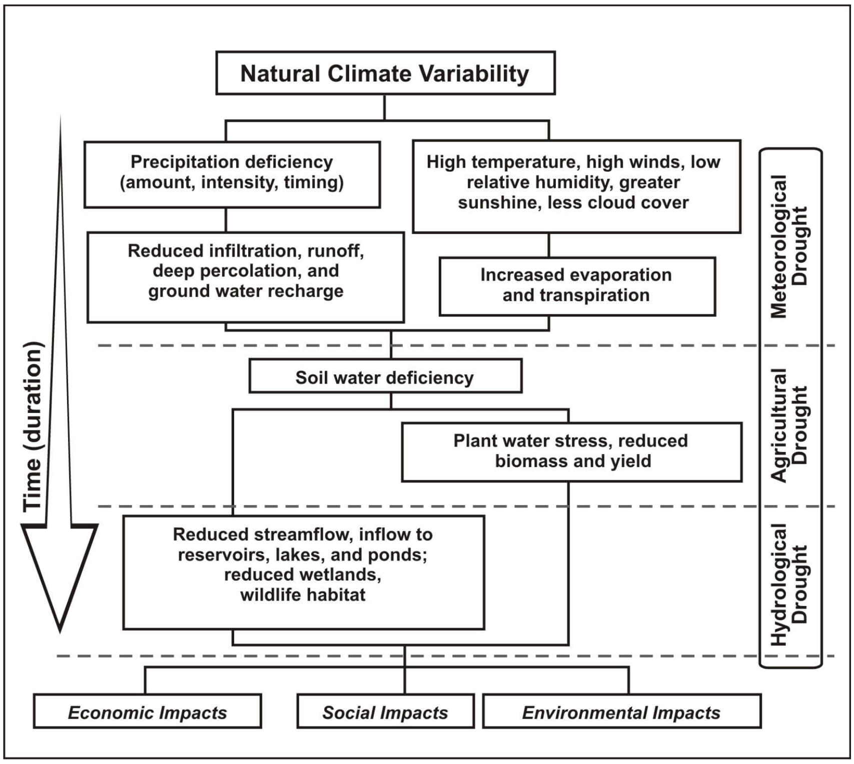

FIGURE 1.2: Sequence of drought occurrence and impacts for commonly accepted drought types. Source: (NDMC, 2023a)

The shown economic, social and environmental impacts of drought in figure 1.2 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). Water scarcity is described in more detail in the following chapter.

1.2.2 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). The focus here is primarily on physical water scarcity, with the social and economic components being outsourced to the broader concept of water security and insecurity (Caretta et al., 2022). In contrast, the Food and Agriculture Organization of the United Nation (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 scarcity 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. Economic water scarcity on the other hand occurs when inadequate infrastructure, institutional or financial capital impede access to water resources "even though water in nature is available to meet human demands" (Molden et al., 2007, p. 11).

Water scarcity and drought can be linked in complex ways. Potential mutual reinforcements, climate change, increased water use and poor water management can further make it difficult to clearly separate these concepts (IDMP, 2022; Leal Filho, Totin, et al., 2022; Liu 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 (FAO, 2012; IDMP, 2022; UNDRR, 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 but together with inadequate access highlights further challenges in ensuring water security (Caretta et al., 2022; Liu & Zhao, 2020; Mishra et al., 2021).

1.2.3 Water Quality & Access

As could be seen in the previous section, 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 (FAO, 2012; RCRC, 2020). Unlike the previous concepts, water quality has mostly fixed indicators by which the condition can be determined. 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 yet viable for large-scale rural assessments in low-income areas (Tariq et al., 2021; WMO, 2013). 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 (WMO, 2013). Nonetheless, new solutions are being developed to simplify and scale affordable water quality assessments to rural areas (Ighalo & 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, for example, were considered as major causes for contamination of water at source (Zamxaka et al., 2004).

The definition of water access is again a rather challenging undertaking. The World Bank (1997) 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" (p. 254). While both time and distance still play a crucial role in literature when investigating water access (Cassivi et al., 2019, 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 three additional factors namely, affordability, quality, and equitable distribution to the definition of water access to fully understand if users have access to water in daily live. United Nations (2002) links these parameters to the access of 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 (FAO & UN-Water, 2021; IDMP, 2022; World Bank, 2016).

1.2.4 Indicators & Indices

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 & 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 (Svoboda et al., 2016; United Nations University, 2017; Williams & Eggleston, 2017). Indices are developed at regional or national level to take account of specific circumstances, or at international level to understand large-scale phenomena (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 et al., 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. However, the indicator or indices should be aligned with the specific definition when put into practice.

Precipitation, evapotranspiration, soil moisture, lake and groundwater levels, streamflow and vegetation water stress are among the most prominent drought indicators (Observatory, 2017). These and other indicators will be aggregated into various drought indices to adequately describe the different drought stages. Among the most prominent meteorological drought indices are the Standardized Precipitation Index *SPI* together with its extension the Standardized Precipitation-Evapotranspiration Index *SPEI* (NCAR, n.d.-a, n.d.-b; Observatory, 2017). These indices compare the standardized departure of observed accumulated precipitation (and evaporation in the case of SPEI) from reference data for a given time period (NCAR, n.d.-a, n.d.-b). 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 et al., 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 Integrated Drought Management Programme (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 socio-economic vulnerabilities (Enenkel et al., 2020). (Mishra et al., 2021) argue, that the framing of water security challenges extends beyond singular indicators. (Lackstrom et al., 2022) take this argument further, in saying 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 describes the supply side effects of water scarcity. However, variabilities,

demand and socio-economic 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; Liu 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 et al., 2003).However, the information on all these indicators is not always available and they often remain quite coarse spatially, making them mostly unsuitable for operational measures.

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 et al., 2016). Besides the pure description of what certain natural or social circumstances **are**, there is a growing interest to understand what these conditions will **do** (Boult et al., 2022; Lackstrom et al., 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 are generally difficult to quantify economically (UNDRR, 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 et al., 2016; UNDRR, 2021). This concept is generally expressed by the risk equation

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

where

$$Vulnerability = f(Level\,of\,Coping\,Capacity,\ Level\,of\,Adaptive\,Capacity)$$

(Boult et al., 2022; Harrowsmith et al., 2020; UNDRR, 2021)

The *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 assess 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 up-to-dateness of the data basis (Harrowsmith et al., 2020).

An understanding of the severity of droughts and their current local impacts enables targeted responses as well as to allow for the development of future predictions based on current conditions. However, most of the current drought or water scarcity indicators do not capture the required level of detail and impact that is required to operationally act upon (Bartram et al., 2014; Mishra et al., 2021). Also, while the complexity of these concepts is due to the level of complexity of the surveyed phenomenon, its application and comparison is hindered. Thus a method to assess local impact, that builds and incorporates these concepts in a practically applicable manner is needed to better facilitate recent efforts that increasingly emphasize proactive and forward-looking measures in disaster relief initiatives. The forthcoming section will explore this relatively recent shift towards proactivity and its implications for improving drought and water management strategies.

1.3 Forecast based Financing

Traditionally, disaster management efforts have primarily focused on long-term preparedness or post-disaster response, thus only providing direct assistance and relief to affected communities after a disaster has occurred (Coughlan de Perez et al., 2015; UNISDR, 2005). The lack of standardized procedures for forecast-based actions led to disaster warnings often going unheard (Kolen et al., 2013). In the context of increasing frequency and severity of natural disasters, coupled with the influences of climate change, the need for a more proactive approach that can reduce the impact of disasters on vulnerable communities became apparent (Coughlan de Perez et al., 2015; Trisos et al., 2022).
Nonetheless, for the time being, funding was strongly focused on the post-disaster response and incentives to invest in new and complex scientific developments including relatively high uncertainties were limited (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" (p.12) became one of seven global targets of the Sendai for Disaster Risk Reduction 2015-2030 framework (UNDRR, 2015). 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 (CREWS, n.d.; World Bank, n.d.). Forecast based Financing has thus emerged as a promising approach to disaster management that enables proactive, timely, and cost-effective responses to disasters (Coughlan de Perez et al., 2015; GRC, 2017). The International Federation of Red Cross and Red Crescent Societies (IFRC) together with the Red Cross Red Crescent Climate Centre (RCRCCC) and German Red Cross (GRC) have developed and improved the FbF programme to

fund EAs since 2007 (IFRC & GRC, 2019).

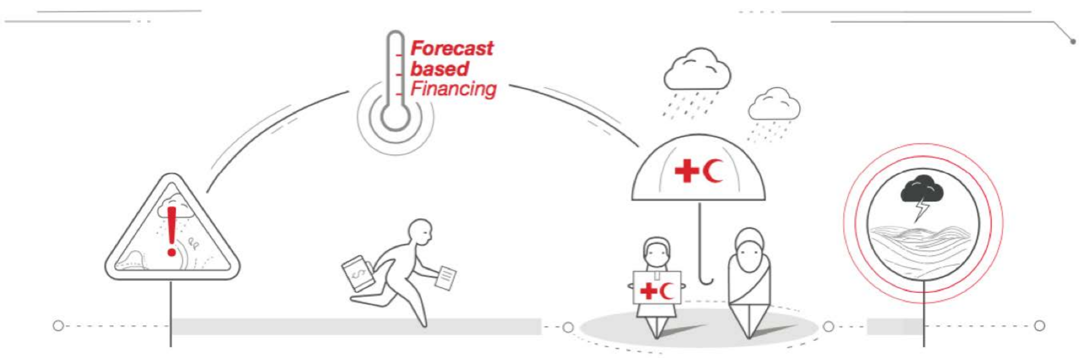

FIGURE 1.3: FbF Diagram. Source: (RCRC, 2020)

Following (Coughlan de Perez et al., 2015; 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." (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 (see figure 1.4 and IFRC and GRC, 2019). Early Action Protocols provide a summary of the three components (Rüth et al., 2017).

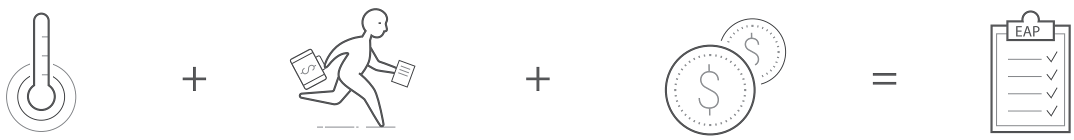

FIGURE 1.4: Early Action Protocol. Source: (IFRC & GRC, 2019)

1.3.1 Early Action Protocol

In the Early Action Protocol (EAP) triggers, actions to be taken and financing mechanisms are clearly outlined. In addition, responsibilities are summarised and explicitly assigned to involved actors to ensure that everyone knows and understands their role and task in case of activation (Rüth et al., 2017). This leads to 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 1.5).

Both, forecasts and risk assessments are primarily based on historic data and experiences. To identify suitable forecasts, different forecasts are compared and examined for their ability and

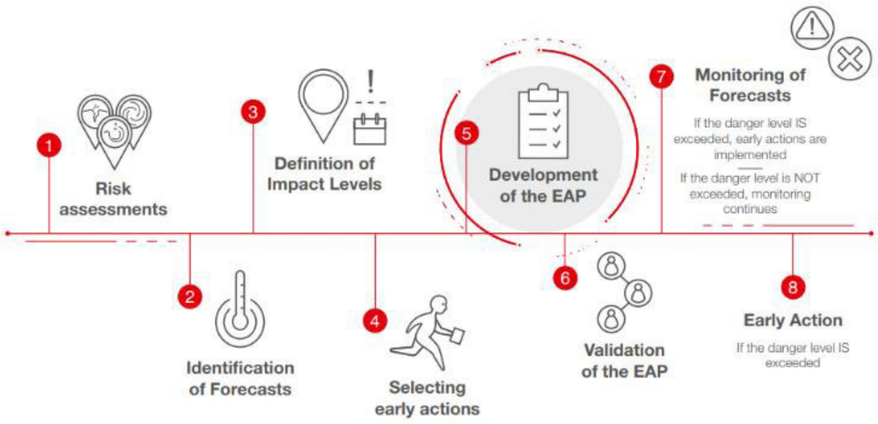

FIGURE 1.5: Overview of EAP development stages. Source: (GRC et al., 2019)

performance in predicting past hazards. 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, see section 1.2.4 (IFRC & GRC, 2019; IFRC et al., 2023b).

The risk assessment is a complex analysis that takes into account numerous factors on the scale of the hazard and its sub-hazards, exposure, and vulnerability with its coping and adaptive capacities (IFRC et al., 2023b). Possible bases for analysis strongly depend 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 is to identify the relevant impacts and their magnitude in order to determine the most effective measures and allocate resources as objectively as possible. However, most of these parameters are proxies, as direct information on local impacts is rare, outdated, of low accuracy or quality (IFRC et al., 2023b).

Due to the majority of the implemented EAPs concentrating on fast onset disasters such as floods, hurricanes or strong rains, the Forecast based Financing concept was primarily focussed and developed in this regard. In this context, a solitary trigger and its corresponding actions are typically established, with a strong emphasis on rapid response given the narrow window of less than 48 hours between activation and the potential onset of 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 selecting actions are further outlined in the coming chapters.

The specification of the financing mechanism as one of the three key components that will not be covered in any further detail in this work, as this is covered and decided by the overlying EAP development. Generally, the IFRC has extended their Disaster Relief Emergency Fund (DREF) with Forecast based Action (FbA) 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. This solves the issue of financing to a large extent and is therefore no longer a major restriction for FbF projects.

1.3.2 Forecast Selection

Indicators and indices as discussed in chapter 1.2.4 measure the severity, duration and spatial coverage of hazard conditions based on historical and current data. They provide a snapshot of past and present conditions and serve as an indicator of the overall situation. Forecasts, on the other hand, use these indices together with climate models and 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 et al., 2020; Yuan et al., 2008). These conditions are mostly collected through satellite and global weather monitoring networks often utilizing drought indices such as the SPI, SPEI and EDDI indices (J.-S. 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 developments and their impacts (ICPAC, 2023; NIDIS, 2023; Observatory, 2017). 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 operationalized (IFRC et al., 2023b). Practically, this changes the information that a forecast provides from predicting e.g. precipitation patterns to forecasting the magnitude and spatial coverage of crop failure, for example (Harrowsmith et al., 2020). The challenges of functional relationships, complex interconnected cause and effect networks and data availability mentioned in section 1.2.4 are also applicable here. Yet, the change to impact-based information provides multiple benefits to practitioners as impact-based forecasts help with the identification and prioritization of areas and communities most severely impacted. This can support a transparent, evidence-based, sector- and context-specific decision-making process directly addressing the communities most in need (IFRC et al., 2023b).
(Boult et al., 2022) further argues 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. In order to put predictions into actions, defining thresholds for triggering Anticipatory Action need to accompany the forecast selection procedure.

1.3.3 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 Anticipatory 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 shown by e.g. the proposed dynamic framework of (Boult et al., 2022). Generally, good conditions for effective trigger development are sufficient historical data, knowledge about local livelihoods including how diverse parts of communities are influenced differently, thorough identification of differentiated impact drivers and their correlation to magnitudes as well as trustworthy forecasts (Coughlan de Perez et al., 2015; Coughlan de Perez et al., 2016; Harrowsmith et al., 2020; RCRC, 2020; Stephens et al., 2015).
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" (Svoboda et al., 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 buildings. Though, in an inanimate area this overflow may only inundate open space and thus lead to no impact at all (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 1.6) (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 1.6. 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 Forecast based Action (FbA)" (p.30) by "thinking outside the box in terms of both hydro-meteorological and socio-economic indicators" (p.31) as the trigger development is still ongoing, even within the RCRC.

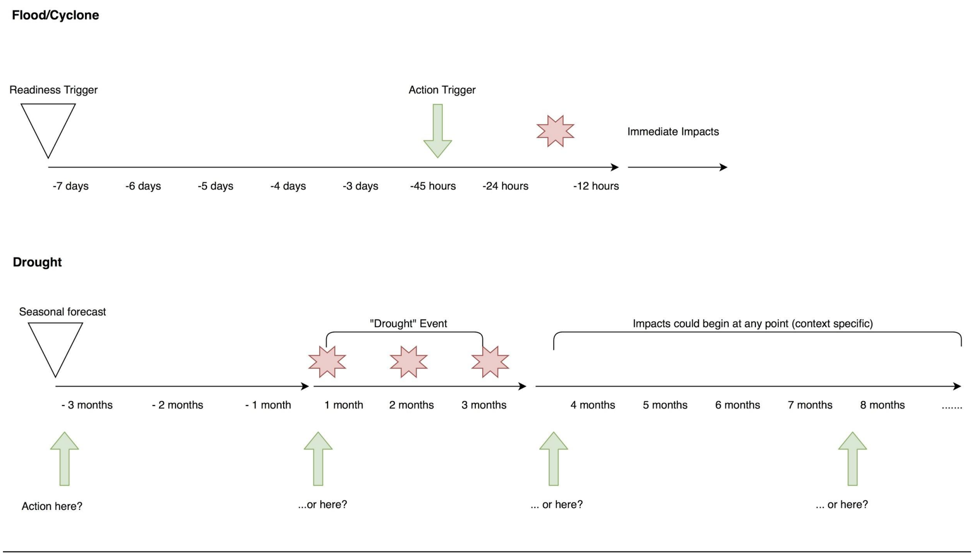

FIGURE 1.6: Time differences between slow- and fast-onset hazards. Source: (RCRC, 2020)

1.3.4 Anticipatory Actions

Anticipatory Actions are at the heart of every EAP and their execution is what everything else is working towards. The goal of every Anticipatory Action is to support 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 AAs is defined, they are again assessed in detail, reflected and decided on with stakeholders and ultimately finalised. Together with an evaluation phase and the definition of prediction and triggers, it is often a simultaneous and iterative process that does not end with the operationalisation of the EAP (IFRC et al., 2023c, 2023d; RCRC, 2020; Stephens et al., 2015).

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 preparation activities, such as the prepositioning of water tablets before the rainy season (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 (IFRC et al., 2023c; Stephens et al., 2015). 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. In the event that a probability threshold is reached, the AAs are triggered and carried out but the disaster does not occur or occurs somewhere else, is generally referred to as *"acting in vain"* (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 (Stephens et al., 2015). Albeit, a growing body of evidence suggests that the benefits of AAs outweigh the costs substantially (Cabot Venton, 2018; 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 either allocate the actions more precisely or increase the general benefits. (IFRC et al., 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.

1.4 Citizen Science

The inclusion of local knowledge in the system of Early Warning and Anticipatory Action may result in many benefits as already mentioned in the end of chapter 1.2.4. 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 et al., 2013; IDMP, 2022; Lackstrom et al., 2022; Leal Filho, Barbir, et al., 2022; Leal Filho, Totin, et al., 2022). One way to include local knowledge is through Citizen Science (CS), 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 et al., 2006; Silvertown, 2009). Since around 2000, the number of publications in regard to CS has risen substantially and CS 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 CS 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 CS 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 field of study, natural research and conservation, is the orientation most frequently related to CS with overlapping concepts to community-based, volunteer and participatory monitoring. It has common interests with the second field of Volunteered Geographic Information (VGI) in topics such as crowdsourcing and data quality whereas the third field of study mostly resolves around public engagement with intersections to CS in public participation (Kullenberg & Kasperowski, 2016).
In order to highlight the core of CS alongside the different disciplinary orientations of the research, different frameworks, guidelines and levels of participation have been designed and defined. (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 clusters (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, n.d.; ESCA et al., 2020; “EU-Citizen.Science”, 2023; Fraisl et al., 2022; García et al., 2021; 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, CS 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 & Hilchey, 2011; Minkman, 2015; Renn, 2006, p. 1).
Current challenges and limitations in CS 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 are just some important aspects to consider (Fraisl et al., 2022). Furthermore, both 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, participant 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 et al., 2017; Weeser et al., 2018).

1.4.1 Community-Based Monitoring (CBM)

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 & 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 & Hilchey, 2011; Koehler & Koontz, 2008; Muhamad Khair et al., 2021; Shirk et al., 2012; Weston & 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 section 1.4.2) and a management aspect which promotes the incorporation of the

generated information into community decision-making processes (C. Conrad, 2007; Keough & 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, n.d.; Fraisl et al., 2022; Minkman, 2015; Pettibone et al., 2016). Here, the challenges, benefits and capabilities of the CBM approach are compared with the problems 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 (Minkman, 2015). Nonetheless, the diversity of this approach means that other goals can be pursued and achieved apart from the main interests. 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; Minkman, 2015). 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 Design 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 CS projects remains unclear up until today. 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, participant 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, n.d.; Fraisl et al., 2022; García et al., 2021; 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. Regardless of this, their adequate integration is seen as a cornerstone of any CBM project (Land-Zandstra et al., 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 (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 & 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 (Land-Zandstra et al., 2021; Minkman, 2015; Mloza-Banda & Scholtz, 2018; Rutten et al., 2017; Tipaldo & Allamano, 2017; D. W. Walker et al., 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 (Minkman, 2015; Rotman et al., 2012; Rutten et al., 2017). According to (Rotman et al., 2012)'s 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 (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 et al., 2021; 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. (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 et al., 2022).

Data Management and common data quality concerns can also be addressed through supervision, external or mutual feedback and preceding training of participants (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 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 analysing 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 et al., 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 sections.

1.4.2 Mobile Crowdsensing (MCS)

Crowdsourcing originated in 2006 from an article by (Howe, n.d.) 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). Due to the merely perceiving and transferring and not further interpreting character, *Crowdsourcing* is on the lower levels of participation. 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; 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 & Jonoski, 2012; Capponi et al., 2019; Liu et al., 2018; Minkman, 2015; Noureen & 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 & Jonoski, 2012; 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.

1.4.3 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 nowadays 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 et al., 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 & 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 (Bennett, 2010; contributors, n.d.). Additional contemporary developments include the concept of MCS in citizen participation, Smart Cities, resource management, transport and behaviour evaluation and many more (Commission, 2021; DIPAS, 2023; 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 platform in Somalia, 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 & 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 & 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 when 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, in low-resource or conflict-affected areas, where the full range of benefits can be

brought to bear, the use of CBS can be of particular advantage. CBS showed promising capacities to address current gaps in health related information, early warning capabilities 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 (Jung et al., 2022). 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 & 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. The current CBS data 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 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

$$health\,risk/event\,\#\,sex\,\#\,age$$

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 & 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 1.7.

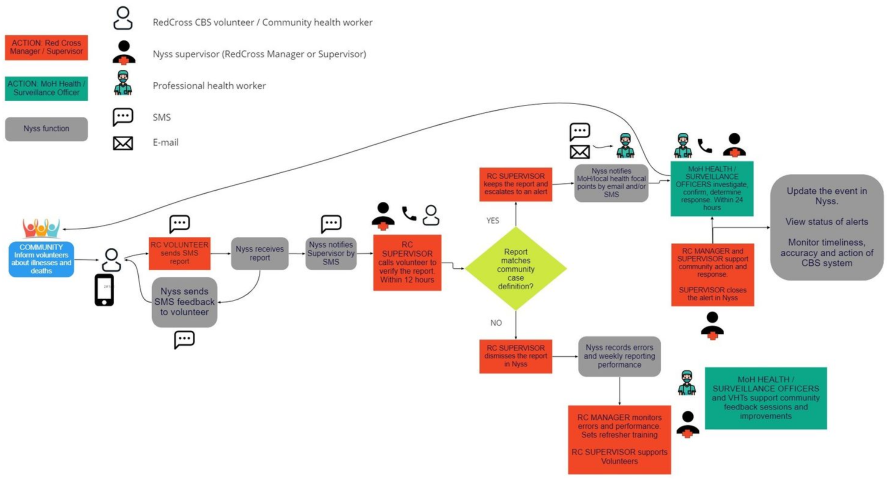

FIGURE 1.7: Sequence diagram of NYSS. Source: (NRC & IFRC, 2023)

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 allows further supervision. Fast and simple escalation of warnings to health officials and other organizations is facilitated through their close integration into the platform (NRC & IFRC, 2021, 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 and based on a Microsoft Azure storage solution. The SMS are received 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 messages to an email-to-sms service which sends the information back to the volunteer (NRC, 2020, January 30/2023; NRC & IFRC, 2021, 2023). The source code, along 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 (Canada et al., 2018; Kirschke et al., 2022; Koehler & Koontz, 2008). CBWM practices range from small monitoring projects to integrated partnerships or councils for the management of watersheds (Weston & 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 & 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).

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 the 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 & 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. All municipalities expressed the system as beneficial exemplifying the usefulness of fast, easy and low resource-intensive communication possibilities in such a context.
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 CBWM 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 operationalisable version of IWRM called 'light IWRM' (Butterworth et al., 2010; Moriarty et al., 2004) and its practical component of Water safety plans (WSP) (Bartram, 2009), (Day, 2009) created a community-based water resource management framework (see figure 1.8).

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 and also takes internal communal heterogeneity and inequalities into account, making it a good conceptual basis for this works water source monitoring design approach. The general usefulness and practical applicability of this framework is indicated by (Oxfam, 2009), as they

TABLE 1.1: Selection of compared Citizen Science projects. Source: Own representation

Name	Country	Interest	Requirements	source
CreekWatch	Canada	Environmental monitoring, water quality	Internet access, Iphone applicaton	(S. Kim et al., 2011)
CoCoRaHS	USA & Canada	Precipitation, condition, drought monitoring	Internet access, local knowledge, measurement equipments	(Lackstrom et al., 2022)
Texas Stream Team (TST)	USA	Environmental monitoring, water quality	Measurement equipment	(Lopez, 2021)
Smart Water Crowdsensing Project	USA	Groundwater monitoring	Internet access, measurement equipment	(Speir et al., 2022)
Social.Water	USA	Hydrologic measurements	Mobile phones	(Fienen & Lowry, 2012)
CrowdHydrology	USA	Hydrologic monitoring	Mobile phones	(Lowry et al., 2019)
Cooperative Observer Program	USA	Weather and climate observations	Mobile phones, Internet access	(Lawrimore et al., 2020)
Haltwhistle Burn Citizen Science	UK	Water, Environmental risks	Internet access	(Starkey et al., 2017)
CS in Water Quality Monitoring	Netherlands	Water quality monitoring	Measurement equipment	(Minkman, 2015)
MAppERS	Denmark	Flood risk monitoring	Internet access, Android application	(Frigerio et al., 2018)
SIMILE APP	Italy	Lake water quality monitoring	Internet accesss, mobile phones	(Carrion et al., 2020)
Citizen science in Kenya	Kenya	Hydrological monitoring	Mobile phone	(Weeser et al., 2018)
ITIKI	Sub-Saharan Africa	Drought prediction, early warning	Mobile phone app, wireless sensors, gauging stations	(Masinde & Bagula, 2012)
Smartphone-based System for water quality analysis	Rajasthan, India	Water quality monitoring	Smartphone, Measurement equipment	(Srivastava et al., 2018)
Ushahidi	worldwide	Disaster Management	Mobile phone, backend self service	(Ushahidi, n.d.)
Sahana Eden	worldwide	Disaster Management	Internet access, self-hosted	(Foundation, 2016)

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 & Conrad, 2015).

Further 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 & Chimbari, 2016; Manalo, 2013; Pineda, 2015; Smith et al., 2017; Tarchiani et al., 2020; Trogrli & 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 (Foundation, 2016; Organization, n.d.; Ushahidi, n.d.). A smaller but dedicated approach to bridge indigenous knowledge and modern science by disseminating early drought information and warnings is the ITIKI (Information Technology and Indigenous Knowledge with Intelligence) framework (Akanbi & Masinde, 2018; Masinde, 2014; Masinde & Bagula, 2010, 2012; Masinde & Thothela, 2019; Masinde et al., 2013,

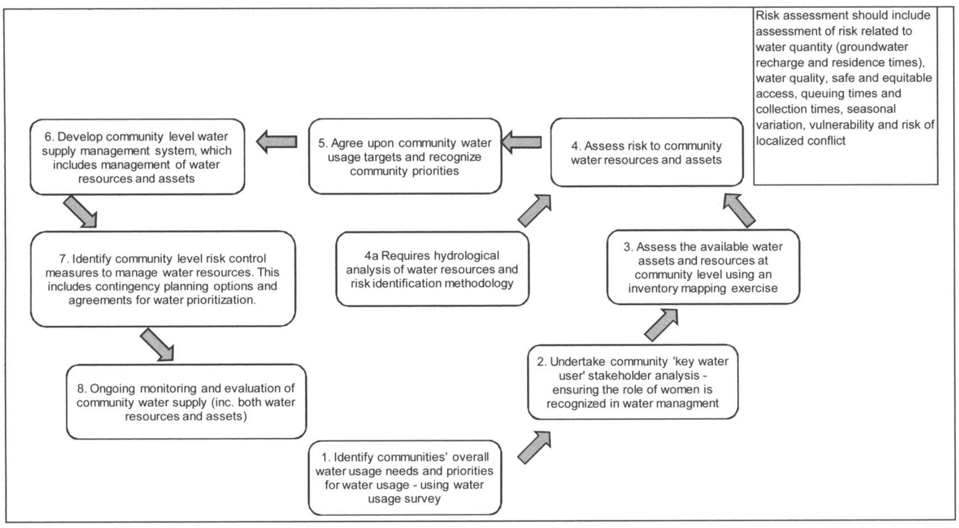

FIGURE 1.8: Community-based water resource management. Source: (Day, 2009)

2018; Nyetanyane & Masinde, 2020; 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 study while also mentioning, that local capacities or pre-conditions often limited a positive respond to the early warning.

(Gladfelter, 2018; Inayath, 2018) and (Trogrli & 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 only specific people or groups 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 along with the MCS NYSS application has thus shown that CBM and MCS can be successfully applied in the local context. CBWM and CBDRR approaches have further demonstrated the potential adaptability of CBM and MCS to water monitoring and risk reduction issues. More on the regional implementation in sections 1.5.5 and **??**.

1.5 Case Study Somaliland

Northern Somalia, also known as Somaliland, is a region located in the Horn of Africa. The self-proclaimed Republic of Somaliland is an independent, de facto sovereign state, but it is not recognised internationally and continues to be considered part of Somalia. Somaliland is bordered by the Gulf of Aden to the north, the Puntland region 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 calculation and source (Petrucci, 2022; Republic of Somalia, 2021; SCRS, 2022). Administratively, Somaliland is divided into five regions according to internationally recognised regulations, from east to west and from north to south: Awdal, Woqooyi Galbeed, Todgheer, Sanaag and Sool with the capital Hargeisa in Woqooyi Galbeed (see figure **??**) (Republic of Somalia, 2021). Somaliland's own constitution divides the country into 6 regions where Woqooyi Galbeed is further divided into Maroodijeex (Hargeisa region) and Sahil (Republic of Somaliland, 2019).

Somaliland map with all the fancy stuff pllllls

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.

1.5.1 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 (Republic of 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; Republic of 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, a challenging climate, and little water resources stress the local fauna, flora and human population.

1.5.2 Water Sources

Often insufficient knowledge about hydrogeological conditions and access depths of more than 100 m caused a rather limited number of boreholes in Somaliland (see section **??**)(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 to store part of the precipitation 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 & Sugule, 1998). Missing prevention mechanisms during the filling process can result in contamination of the water with organic matter, animal or human faeces etc. (Corps, 2017). The lack of separation between animals and people can also lead to contamination during water extraction. Improved designs are available, and more sophisticated versions nowadays use concrete, are properly roofed to counteract evaporation and pollution, and have adequate inflow and outflow 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 & Sugule, 1998) estimated about 12.000 berkads clustered in 126 groups in the ethiopian district in Gashaamo, which borders Somaliland in the south. (Birch, 2008) notes 7000 berkads for the Hawd region. Although both with an unknown number of non-operational berkads, the sheer number and reliance of pastoralists and communities on berkads mentioned by (R. Walker & 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 partly contradict each other, are limited, mostly outdated and unknown in quality (see section **??**)("FAO SWALIM: Somalia Water and Land Information ManagementFAO SWALIM: Somalia Water and Land Information Management", n.d.).

1.5.3 Political & Social Affairs

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 who, from a supremacy of the southern part, cruelly and partly arbitrarily suppressed the northern one, Somaliland. Arrests, mine water points and executions culminated in the genocide of thousands of members of the largest clan, the Isaaq tribe (Peifer, 2009; Republic of 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 is challenged in recent times due to the postponement of elections (BBC, 2022; Forti, 2011). Though, internal conflicts and border disputes with Puntland in the east continue until today (Filho & 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 House of Elders (Salem, 2016).
Somaliland has a GDP of approx. 1.5-2$ billion, mostly based on remittances from Somalilanders working abroad and with the main export being livestock, per capita income is only in the hundreds of dollars (Klobucista, 2018; Republic of Somalia, 2021; World 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 (Republic of Somalia, 2021; World 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 (USAID, 2018).

1.5.4 Hazards & 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 times (Abdulkadir, 2017). Several historical and current analyses and predictions indicate, that these phenomena will not decrease 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 & Jemal, 2017; Balint et al., 2013; Committee, 2022; Erian et al., 2021; "FAO SWALIM: Somalia Water and Land Information ManagementFAO SWALIM: Somalia Water and Land Information Management", n.d.; Musei et al., 2021; Trisos et al., 2022). Population growth, deforestation and desertification, groundwater depletion and land grabbing further stresses the situation (Ali & 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", n.d.). 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 over 800.000 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 & Jemal, 2017), (Abdulkadir, 2017) as well as by the growing community of Forecast based Financing practitioners (Gualazzini, 2021; Harrowsmith et al., 2020).

1.5.5 Preventive Measurements

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 (Hillbruner & Moloney, 2012; Stephens et al., 2015). Subsequent evaluations point to two main areas of concern. On the one hand, there was a lack of timely funding, and 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 (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 et al., 2023a)), merging experiences of pilot projects to adjust guidelines for the development of FbF and Anticipatory 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 (RCRC, 2020; L. R. C. Society & IFRC, 2022; N. R. C. Society & IFRC, 2021).
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 good postition 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. 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, and 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 (RCRC, 2020; SCRS, 2022).

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 & 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 & 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 (FAOSWALIM, 2014; SCRS, 2022). 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 (SCRS, 2022). 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 & IFRC, 2022; N. R. C. Society & 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 and will further 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 of 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 (SCRS, 2022). 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 the absence of a internationally approved abattoir which limits the amount saleable meat to local market capacities (SCRS, 2022). (Gualazzini, 2021) propose water vouchers 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).
Neben the mentioned forecasts of natural phenomena, SRCS has successfully set up a CBS project to monitor and react to disease outbreaks on community level since 2018 (see section 1.4.3 and (Jung et al., 2022)).

Alongside SRCS and IFRC, OCHA and BRCiS also developed anticipatory action plans for Somalia in recent years. OCHA followed conventional frameworks in regard to forecasts and triggers with their pilot study in 2020 , 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 it (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 informant interviews 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 and is assessed at the end of the 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)* allowing for a seasonal prediction and corresponding flagging.

1.6 Literature Summary

This chapter outlined the overall theoretical background of the case studies context by starting with the concepts of Water Security, Water Scarcity and Drought. These are wide ranging concepts, complex in nature and various definitions exist for each of these. Water Security links an extensive network of interrelated trans- and inter-sectoral systems together and can be seen as umbrella term for the extensive web around water availability and its many components. Water Scarcity, as it is understood in this work, has a physical and economic aspect which refer to the availability of water resources and the various economic conditions for its extraction, respectively. Therefore, the absolute lack of water in the current situation, water shortage, always has a human (long-term) dimension, particularly on the demand side. Drought is most often considered in four stages, namely meteorological, agricultural, hydrogeological and socio-economic drought with each having their specific sets of impacts, indicators and indices. Drought, as natural hazard, is differentiated to aridity by its short but severe nature. Conceptual definitions give an idea and set boundaries to the concept of drought while operational definitions focus on its onset, duration, severity and spatial coverage.

Measuring and predicting droughts is complex and often multiple individual or sets of indicators and indices are combined to get a full picture of the situation. Indices are themselves often composites of multiple indicators and mathematical functions. The intricate and interconnected nature of droughts leads to uncertainties in forecasts, making it more difficult to define impact thresholds for anticipatory measures. Impact is generally expressed by a combination of hazard severity, the exposure of assets and their vulnerability. The latter three often summarized in the term risk.

Forecast based Financing (FbF) is a relatively newly emerged phenomena in the realm of humanitarian aid that promotes Anticipatory Actions before the impact. This is based on a hazard and risk pre-assessment to identify thresholds on which to trigger pre-defined actions that ultimately help to reduce the impact, documented and defined in an Early Action Protocol. For successful implementation, triggers and actions should be developed together and directly coupled. In the context of water sources in Somaliland, this is generally not feasible as local information data is either outdated or missing completely.

Citizen Science (CS) is the involvement of citizens in scientific or public endeavours and can promote various benefits to all engaged stakeholders if implemented and operated correctly. Citizen Science, similar to the above concepts, is wide-ranging and complex. Under this umbrella, Community-based Surveillance (CBS) together with Mobile Crowdsensing provide practically realizable frameworks and guidelines for the successful application of CS specifically in regard to remote data collection. CBS and Community-based Water Monitoring (CBWM) demonstrate the feasibility in the local context and transferability of these concepts, respectively.

Somaliland lies within the Great Horn of Africa and can geographically and climatologically be seen as a generally arid and water scarce region with poor soils, scarce vegetation and limited water resources. It has historically been troubled by droughts, as well as internal and external conflicts, which regularly exacerbate the already tense situation. Somaliland is one of the poorest regions in the world but managed to develop a relatively stable democracy for the last 30 years. Currently, many local, national and international organization work on mitigating and responding to a further tense situation with famine expected in mid-2023.

Certain limitations and gaps could be identified in the above conducted literature review. The concepts of Water Security, Water Scarcity and Drought need to be clearly defined and broken down to the specific region and application. Unfortunately, the long history of conflicts and insecurities severely limited scientific research in Somaliland in particular, which generally led to little scholarly information on the region.
While numerous international forecasts exist and local assessments start to emerge, timely, highly local and up-to-date data is not available for many areas of interest. Thus, the direct link of trigger and Anticipatory Actions (AAs) is often not given, making the implementation less effective, efficient, targeted and time consuming.
The concept of FbF is generally well established by now, but the drought use case is new and not yet well researched, which greatly limits the amount of guidelines and frameworks available for this particular application. Thus, each new project and study has, at least in part, an exploratory character.
Citizen Science projects in regard to water are geographically primarily focused on North American and European countries, relating most of the scientific findings to the respective context. Furthermore, these water related projects mainly focus on river, lake or groundwater level or water quality monitoring and not on direct community water source investigations to facilitate AAs. The review of data availability and reliability of current datasets revealed a clear need for more up-to-date and complete information on water source locations and characteristics, especially with regard to the highly important water type of berkads.

Bibliography

Abdulkadir, G. (2017). Assessment of Drought Recurrence in Somaliland: Causes, Impacts and Mitigations. *Journal of Climatology & Weather Forecasting*, *05*(02). https://doi.org/10.4172/2332-2594.1000204

Aceves-Bueno, E., Adeleye, A. S., Bradley, D., Tyler Brandt, W., Callery, P., Feraud, M., Garner, K. L., Gentry, R., Huang, Y., McCullough, I., Pearlman, I., Sutherland, S. A., Wilkinson, W., Yang, Y., Zink, T., Anderson, S. E., & Tague, C. (2015). Citizen Science as an Approach for Overcoming Insufficient Monitoring and Inadequate Stakeholder Buy-in in Adaptive Management: Criteria and Evidence. *Ecosystems*, *18*(3), 493–506. https://doi.org/10.1007/s10021-015-9842-4

Akanbi, A., & Masinde, M. (2018, August 7). *Towards the Development of a Rule-Based Drought Early Warning Expert Systems Using Indigenous Knowledge*. https://doi.org/10.1109/ICABCD.2018.8465465

Albus, K. H., Thompson, R., Mitchell, F., Kennedy, J., & Ponette-González, A. G. (2020). Accuracy of long-term volunteer water monitoring data: A multiscale analysis from a statewide citizen science program. *PLOS ONE*, *15*(1), e0227540. https://doi.org/10.1371/journal.pone.0227540

Alfonso, L., & Jonoski, A. (2012, July 14). *MOBILE PHONE APPLICATIONS FOR WATER MANAGEMENT: CLASIFFICATION, OPPORTUNITIES AND CHALLENGES*.

Ali, N. M., & Jemal, K. (2017). Mitigating Natural Disasters in Somaliland Policy Options and Strategies, 8.

Allen, K. (2018). *Community-Based Water Monitoring and Decision Making*. Environmental Law Centre, University of Victoria.

Anderson, W. B., Han, E., Baethgen, W., Goddard, L., Muñoz, A. G., & Robertson, A. W. (2022). The Madden-Julian Oscillation affects crop yields around the world. *Authorea Preprints*.

Andersson, L., Wilk, J., Graham, L. P., Wikner, J., Mokwatlo, S., & Petja, B. (2020). Local early warning systems for drought Could they add value to nationally disseminated seasonal climate forecasts? *Weather and Climate Extremes*, *28*, 100241. https://doi.org/10.1016/j.wace.2019.100241

Arreguin-Cortes, F. I., Saavedra-Horita, J. R., Rodriguez-Varela, J. M., Tzatchkov, V. G., Cortez-Mejia, P. E., Llaguno-Guilberto, O. J., Sainos-Candelario, A., Sandoval-Yoval, L., Ortega-Gaucin, D., Mendoza-Cazares, E. Y., & Navarro-Barraza, S. (2019). Municipal level water security indices in Mexico. *SN Applied Sciences*, *1*(10), 1194. https://doi.org/10.1007/s42452-019-1180-2

Association), E. (C. S. (2015). Ten Principles of Citizen Science. https://doi.org/10.17605/OSF.IO/XPR2N

Baalbaki, R., Ahmad, S. H., Kays, W., Talhouk, S. N., Saliba, N. A., & Al-Hindi, M. (2019). Citizen science in Lebanona case study for groundwater quality monitoring. *Royal Society Open Science*, *6*(2), 181871. https://doi.org/10.1098/rsos.181871

Balint, Z., Mutua, F., Muchiri, P., & Omuto, C. T. (2013). Monitoring Drought with the Combined Drought Index in Kenya. In *Developments in Earth Surface Processes* (pp. 341–356, Vol. 16). Elsevier. https://doi.org/10.1016/B978-0-444-59559-1.00023-2

Balti, H., Abbes, A., Mellouli, N., Farah, I., Sang, Y., & Lamolle, M. (2020). A review of drought monitoring with big data: Issues, methods, challenges and research directions. *Ecological Informatics*, *60*, 101136. https://doi.org/10.1016/j.ecoinf.2020.101136

Baptiste, S., Manouan, A., Garcia, P., Etyaale, H., Swan, T., & Jallow, W. (2020). Community-Led Monitoring: When Community Data Drives Implementation Strategies. *Current HIV/AIDS Reports*, *17*(5), 415–421. https://doi.org/10.1007/s11904-020-00521-2

Bartram, J. (2009). *Water safety plan manual: Step-by-step risk management for drinking-water suppliers*. World Health Organization.

Bartram, J., Brocklehurst, C., Fisher, M. B., Luyendijk, R., Hossain, R., Wardlaw, T., & Gordon, B. (2014). Global Monitoring of Water Supply and Sanitation: History, Methods and Future Challenges. *International Journal of Environmental Research and Public Health*, *11*(8), 8137–8165. https://doi.org/10.3390/ijerph110808137

Baudoin, M.-A., Henly-Shepard, S., Fernando, N., & Sitati, A. (2014). Early warning systems and livelihood resilience: Exploring opportunities for community participation. Retrieved October 26, 2022, from https://collections.unu.edu/view/UNU:3174#viewMetadata

BBC. (2022). Somaliland profile [newspaper]. *BBC News: Africa*. Retrieved March 21, 2023, from https://www.bbc.com/news/world-africa-14115069

Bennett, J. (2010, September 22). *OpenStreetMap*. Packt Publishing Ltd.

Birch, I. (2008). Somaliland/Somali Region Desk Review.

Blauvelt, R. (2014). Systematizing Environmental Indicators and Indices. *Journal of Environment and Ecology*, *5*, 15. https://doi.org/10.5296/jee.v5i1.4864

Boetzelaer, E. V., Chowdhury, S., Etsay, B., Faruque, A., Lenglet, A., Kuehne, A., Carrion-Martin, I., Keating, P., Dada, M., Vyncke, J., Kazungu, D. S., & Verdecchia, M. (2020). Evaluation of community based surveillance in the Rohingya refugee camps in Coxs Bazar, Bangladesh, 2019. *PLOS ONE*, *15*(12), e0244214. https://doi.org/10.1371/journal.pone.0244214

Botai, O., Botai, C., Wit, J., Masinde, M., & Abiodun, A. (2019). Analysis of Drought Progression Physiognomies in South Africa. *Water*, *11*, 299. https://doi.org/10.3390/w11020299

Boult, V. L., Black, E., Saado Abdillahi, H., Bailey, M., Harris, C., Kilavi, M., Kniveton, D., MacLeod, D., Mwangi, E., Otieno, G., Rees, E., Rowhani, P., Taylor, O., & Todd, M. C. (2022). Towards drought impact-based forecasting in a multi-hazard context. *Climate Risk Management*, *35*, 100402. https://doi.org/10.1016/j.crm.2022.100402

Brabham, D. C. (2008). Crowdsourcing as a Model for Problem Solving: An Introduction and Cases. *Convergence*, *14*(1), 75–90. https://doi.org/10.1177/1354856507084420

Buckingham Shum, S., Aberer, S., Schmidt, K., Jelasity, M., Karpitenko, M., Kohlhammer, A., Lewis, J., Pitt, J., Sumner, J., Buckingham Shum, S., Aberer, K., Schmidt, A., Bishop, S., Lukowicz, P., Anderson, S., Charalabidis, Y., Domingue, J., Freitas, S., Dunwell, I., & Helbing, D. (2012). Towards a global participatory platform: Democratising open data, complexity science and collective intelligence. *The European Physical Journal Special Topics*, *214*, 109–152. https://doi.org/10.1140/epjst/e2012-01690-3

Budde, M., Schankin, A., Hoffmann, J., Danz, M., Riedel, T., & Beigl, M. (2017). Participatory Sensing or Participatory Nonsense? Mitigating the Effect of Human Error on Data Quality in Citizen Science. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, *1*(3), 39:1–39:23. https://doi.org/10.1145/3131900

Butte, G., Solano-Correa, Y. T., Peppa, M. V., Ruíz-Ordóñez, D. M., Maysels, R., Tuqan, N., Polaine, X., Montoya-Pachongo, C., Walsh, C., & Curtis, T. (2022). A Framework for Water Security Data Gathering Strategies. *Water*, *14*(18), 2907. https://doi.org/10.3390/w14182907

Butterworth, J., Warner, J. F., Moriarty, P., Smits, S., & Batchelor, C. (2010). Finding practical approaches to integrated water resources management. *Water alternatives*, *3*(1), 68–81.

Byrne, A., & Nichol, B. (2020). A community-centred approach to global health security: Implementation experience of community-based surveillance (CBS) for epidemic preparedness. *Global Security: Health, Science and Policy*, *5*(1), 71–84. https://doi.org/10.1080/23779497.2020.1819854

Cabot Venton, C. (2018). Economics of resilience to drought in Ethiopia, Kenya and Somalia. *USAID, Washington DC. Available from www. usaid. gov/sites/default/files/documents/1867/Summary_Econo Jan_4_2018_BRANDED. pdf*.

Canada, L. L. (2018). Community-Based Water Monitoring National Survey Highlights, February 2018.

Canada, L. L., Foundation, T. G., & WWF-Canada. (2018). *Elevating Community Based Water Monitoring Featured Case Study*. https://livinglakescanada.ca/wp-content/uploads/2019/04/Case-Studies-Final-Spreads.pdf

Capponi, A., Fiandrino, C., Kantarci, B., Foschini, L., Kliazovich, D., & Bouvry, P. (2019). A Survey on Mobile Crowdsensing Systems: Challenges, Solutions, and Opportunities. *IEEE Communications Surveys & Tutorials*, *21*(3), 2419–2465. https://doi.org/10.1109/COMST.2019.2914030

Caretta, M., Mukherji, A., Arfanuzzaman, M., Betts, R., Gelfan, A., Hirabayashi, Y., Lissner, T., Liu, J., Lopez Gunn, E., Morgan, R., Mwanga, S., & Supratid, S. (2022). Water. In H.-O. Pörtner, D. Roberts, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change* (pp. 551–712). Cambridge University Press. https://doi.org/10.1017/9781009325844.006

Carrion, D., Pessina, E., Biraghi, C. A., & Bratic, G. (2020). CROWDSOURCING WATER QUALITY WITH THE SIMILE APP. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLIII-B4-2020*, 245–251. https://doi.org/10.5194/isprs-archives-XLIII-B4-2020-245-2020

Cassivi, A., Guilherme, S., Bain, R., Tilley, E., Waygood, E. O. D., & Dorea, C. (2019). Drinking water accessibility and quantity in low and middle-income countries: A systematic review. *International Journal of Hygiene and Environmental Health*, *222*(7), 1011–1020. https://doi.org/10.1016/j.ijheh.2019.06.011

Cassivi, A., Tilley, E., Waygood, E. O. D., & Dorea, C. (2021). Evaluating self-reported measures and alternatives to monitor access to drinking water: A case study in Malawi. *Science of The Total Environment*, *750*, 141516. https://doi.org/10.1016/j.scitotenv.2020.141516

CDC. (2022a, March 24). *Assessing Access to Water & Sanitation*. Centers for Disease Control and Prevention. Retrieved March 8, 2023, from https://www.cdc.gov/healthywater/global/assessing.html

CDC. (2022b, November 8). *One Health Basics*. Retrieved March 18, 2023, from https://www.cdc.gov/onehealth/basics/index.html

CitizenScience.gov. (n.d.). *Basic Steps for Your Project Planning*. Retrieved February 3, 2023, from https://www.citizenscience.gov/toolkit/howto/

CoCoRaHS. (2023). *CoCoRaHS - Community Collaborative Rain, Hail & Snow Network*. Retrieved September 28, 2022, from https://www.cocorahs.org/

Commission, E. (2021). *A citizen-centred approach to smart cities | Research and Innovation*. Retrieved March 18, 2023, from https://ec.europa.eu/research-and-innovation/en/projects/success-stories/all/citizen-centred-approach-smart-cities

Committee, N. D. (2022). *SOMALILAND DROUGHT RAPID ASSESSMENT REPORT*. Retrieved March 1, 2023, from https://drive.google.com/file/d/1KWUZW0jEMV1Ijc4zeET_Yes93VJ_3qn2/view?usp=embed_facebook

Conrad, C. (2007). Community-based monitoring and the science of water quality. *IAHS Publ.*, *314*.

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: Issues and opportunities. *Environmental Monitoring and Assessment*, *176*(1), 273–291. https://doi.org/10.1007/s10661-010-1582-5

contributors, O. (n.d.). *OpenStreetMap*. OpenStreetMap. Retrieved March 18, 2023, from https://www.openstreetmap.org/

Corps, M. (2017). IMPROVED BERKAD DESIGNS BY MERCY CORPS - SOMALIA.

Coughlan de Perez, E., van den Hurk, B. J. J. M., Van Aalst, M. K., Jongman, B., Klose, T., & Suarez, P. (2015). Forecast-based financing: An approach for catalyzing humanitarian action based on extreme weather and climate forecasts. *Natural Hazards and Earth System Sciences*, *15*(4), 895–904.

Coughlan de Perez, E., van den Hurk, B., van Aalst, M. K., Amuron, I., Bamanya, D., Hauser, T., Jongma, B., Lopez, A., Mason, S., Mendler de Suarez, J., Pappenberger, F., Rueth, A., Stephens, E., Suarez, P., Wagemaker, J., & Zsoter, E. (2016). Action-based flood forecasting for triggering humanitarian action. *Hydrology and Earth System Sciences*, *20*(9), 3549–3560. https://doi.org/10.5194/hess-20-3549-2016

CRED. (2023). *EM-DAT | The international disasters database*. Retrieved March 21, 2023, from https://www.emdat.be/

CREWS. (n.d.). *Climate Risk and Early Warning Systems*. Retrieved March 9, 2023, from https://www.crews-initiative.org/en

Day, S. J. (2009). Community-based water resources management. *Waterlines*, *28*(1), 47–62. Retrieved February 16, 2023, from https://www.jstor.org/stable/24686845

dictionary of the English language, T. A. H. (2022). Drought. In *The American Heritageő Dictionary of the English Language* (Fifth Edition). Retrieved March 7, 2023, from https://ahdictionary.com/word/search.html?q=drought

DIPAS. (2023). *DIPAS.org | DIPAS*. Retrieved March 18, 2023, from https://dipas.org/

Emenike, C. P., Tenebe, I. T., Omole, D. O., Ngene, B. U., Oniemayin, B. I., Maxwell, O., & Onoka, B. I. (2017). Accessing safe drinking water in sub-Saharan Africa: Issues and challenges in SouthWest Nigeria. *Sustainable Cities and Society*, *30*, 263–272. https://doi.org/10.1016/j.scs.2017.01.005

Enenkel, M., Brown, M. E., Vogt, J. V., McCarty, J. L., Reid Bell, A., Guha-Sapir, D., Dorigo, W., Vasilaky, K., Svoboda, M., Bonifacio, R., Anderson, M., Funk, C., Osgood, D., Hain, C., & Vinck, P. (2020). Why predict climate hazards if we need to understand impacts? Putting humans back into the drought equation. *Climatic Change*, *162*(3), 1161–1176. https://doi.org/10.1007/s10584-020-02878-0

Erian, W., Pulwarty, R., Vogt, J. V., AbuZeid, K., Bert, F., Bruntrup, M., El-Askary, H., de Estrada, M., Gaupp, F., & Grundy, M. (2021). GAR special report on drought 2021.

ESCA, Haklay, M., Motion, A., Balázs, B., Kieslinger, B., Greshake Tzovaras, B., Nold, C., Dörler, D., Fraisl, D., Riemenschneider, D., Heigl, F., Brounéus, F., Hager, G., Heuer, K., Wagenknecht, K., Vohland, K., Shanley, L., Deveaux, L., Ceccaroni, L., … Wehn, U. (2020). ECSA's Characteristics of Citizen Science. https://doi.org/10.5281/zenodo.3758668

EU-Citizen.Science. (2023). Retrieved March 14, 2023, from https://eu-citizen.science/

Falkenmark, M., Lundqvist, J., & Widstrand, C. (1989). Macro-scale water scarcity requires micro-scale approaches. *Natural Resources Forum*, *13*(4), 258–267. https://doi.org/10.1111/j.1477-8947.1989.tb00348.x

FAO. (2012). *Coping with water scarcity: An action framework for agriculture and food security* (P. Steduto, J.-M. Faurès, J. Hoogeveen, J. T. Winpenny, & J. J. Burke, Eds.). Food and Agriculture Organization of the United Nations.
OCLC: ocn822026893.

FAO & UN-Water. (2021, August 23). *Progress on the level of water stress*. Food and Agriculture Organization of the United Nations and UN-Water. https://doi.org/10.4060/cb6241en

FAO SWALIM: Somalia Water and Land Information ManagementFAO SWALIM: Somalia Water and Land Information Management. (n.d.). Retrieved October 26, 2022, from https://www.faoswalim.org/

FAOSWALIM. (2012). *Hydrogeological Survey and Assessment of Selected Areas in Somaliland and Puntland* (Technical Report No. W-20, FAO-SWALIM (GCP/SOM/049/EC)). Nairobi, Kenya.

FAOSWALIM. (2014). *SWALIM: Weather Monitoring*. Retrieved March 22, 2023, from http://www.faoswalim.org/water/climate/climate-data-collection

FEWSNET & USAID. (2023). *Famine Early Warning Systems Network*. Retrieved March 22, 2023, from https://fews.net/

Fienen, M. N., & Lowry, C. S. (2012). Social.WaterA crowdsourcing tool for environmental data acquisition. *Computers & Geosciences*, *49*, 164–169. https://doi.org/10.1016/j.cageo.2012.06.015

Filho, P. P., & Motta, H. O. D. (2021). *DEMOCRACY IN AFRICA: THE OUTSTANDING CASE OF SOMALILAND*. Retrieved October 25, 2022, from https://www.semanticscholar.org/paper/DEMOCRACY-IN-AFRICA%3A-THE-OUTSTANDING-CASE-OF-Filho-Motta/e8b2f10f6c5fbb794f2f88de1ba690b3a6952cf7

Forti, D. R. (2011). A Pocket of Stability: Understanding Somaliland, 49.

Foundation, S. (2016, October 27). *Sahana EDEN*. Sahana Foundation. Retrieved March 20, 2023, from https://sahanafoundation.org/eden/

Fraisl, D., Hager, G., Bedessem, B., Gold, M., Hsing, P.-Y., Danielsen, F., Hitchcock, C. B., Hulbert, J. M., Piera, J., Spiers, H., Thiel, M., & Haklay, M. (2022). Citizen science in environmental and ecological sciences. *Nature Reviews Methods Primers*, *2*(1), 1–20. https://doi.org/10.1038/s43586-022-00144-4

Frigerio, S., Schenato, L., Bossi, G., Mantovani, M., Marcato, G., & Pasuto, A. (2018). Hands-On Experience of Crowdsourcing for Flood Risks. An Android Mobile Application Tested in Frederikssund, Denmark. *International Journal of Environmental Research and Public Health*, *15*(9), 1926. https://doi.org/10.3390/ijerph15091926

García, F. S., Pelacho, M., Woods, T., Fraisl, D., See, L., Haklay, M. M., & Arias, R. (2021). Finding what you need: A guide to citizen science guidelines. *The science of citizen science*, 419.

Gettliffe, E. (2021). UN OCHA anticipatory action. Lessons from the 2020 Somalia pilot.

Giordano, R., Preziosi, E., & Romano, E. (2013). Integration of local and scientific knowledge to support drought impact monitoring: Some hints from an Italian case study. *Natural Hazards*, *69*(1), 523–544. https://doi.org/10.1007/s11069-013-0724-9

Gladfelter, S. (2018). The politics of participation in community-based early warning systems: Building resilience or precarity through local roles in disseminating disaster information? *International Journal of Disaster Risk Reduction*, *30*, 120–131. https://doi.org/10.1016/j.ijdrr.2018.02.022

Gore, M., Abiodun, B., & Kucharski, F. (2020). Understanding the influence of ENSO patterns on drought over southern Africa using SPEEDY. *Climate Dynamics*, *54*. https://doi.org/10.1007/s00382-019-05002-w

GRC. (2017). FORECAST-BASED FINANCING An innovative approach. https://www.drk.de/en/forecast-based-financing/

GRC, CVM, & IFRC. (2019). *2nd African Dialogue Platform on Forecast-based Financing*.

Grey, D., & Sadoff, C. W. (2007). Sink or Swim? Water security for growth and development. *Water Policy*, *9*(6), 545–571. https://doi.org/10.2166/wp.2007.021

Gualazzini, M. (2021). *EWEA: Early Warning Early action technical brief*.

Guenin, M.-J., De Nys, H. M., Peyre, M., Loire, E., Thongyuan, S., Diallo, A., Zogbelemou, L., & Goutard, F. L. (2022). A participatory epidemiological and One Health approach to explore the communitys capacity to detect emerging zoonoses and surveillance network opportunities in the forest region of Guinea. *PLoS Neglected Tropical Diseases*, *16*(7), e0010462.

Guo, B., Yu, Z., Zhou, X., & Zhang, D. (2014). From participatory sensing to mobile crowd sensing. *2014 IEEE International Conference on Pervasive Computing and Communication Workshops (PERCOM WORKSHOPS)*, 593–598.

Haklay, M. (, Dörler, D., Heigl, F., Manzoni, M., Hecker, S., & Vohland, K. (2021). What Is Citizen Science? The Challenges of Definition. In K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, M. Ponti, R. Samson, & K. Wagenknecht (Eds.), *The Science of Citizen Science* (pp. 13–33). Springer International Publishing. https://doi.org/10.1007/978-3-030-58278-4_2

Harrowsmith, M., Nielsen, M., Sanchez, M. J., de Perez, E. C., Uprety, M., Johnson, C., van den Homberg, M., Tijssen, A., Page, E. M., & Lux, S. (2020). The Future of Forecast: Impact based Forecasting for Early Action.

Henriksen, H. J., Roberts, M. J., van der Keur, P., Harjanne, A., Egilson, D., & Alfonso, L. (2018). Participatory early warning and monitoring systems: A Nordic framework for web-based flood risk management. *International Journal of Disaster Risk Reduction*, *31*, 1295–1306. https://doi.org/10.1016/j.ijdrr.2018.01.038

Hillbruner, C., & Moloney, G. (2012). When early warning is not enoughLessons learned from the 2011 Somalia Famine. *Global Food Security*, *1*(1), 20–28. https://doi.org/10.1016/j.gfs.2012.08.001

Howe, J. (n.d.). The Rise of Crowdsourcing [magazine]. *Wired*. Retrieved November 11, 2022, from https://www.wired.com/2006/06/crowds/

Huang, W. W., Chen, X. J., Fan, Y. R., & Li, Y. P. (2020). Management of Drinking Water Source in Rural Communities under Climate Change. *JOURNAL OF ENVIRONMENTAL INFORMATICS*, *39*(2), 136–151. Retrieved November 10, 2022, from http://www.jeionline.org/index.php?journal=mys&page=article&op=view&path%5B%5D=202000431

ICPAC. (2023). *Drought Indicators*. Retrieved March 13, 2023, from https://droughtwatch.icpac.net/drought-indicators/

ICPAC & WMO. (2023). *Delivering Climate Services to Eastern Africa*. ICPAC. Retrieved March 22, 2023, from https://www.icpac.net/

IDMP. (2021). *Indicators and Indices Integrated Drought Management Programme*. Retrieved March 10, 2023, from https://www.droughtmanagement.info/indices/

IDMP. (2022). *Drought and Water Scarcity* (WMO No. 1284). Global Water Partnership, Stockholm, Sweden and and World Meteorological Organization, Geneva, Switzerland.

IFRC & GRC. (2019). Forecast-based Financing A new era for the humanitarian system. https://www.forecast-based-financing.org/wp-content/uploads/2019/03/DRK_Broschuere_2019_new_era.pdf

IFRC, RCCC, & GRC. (2023a). *FbF Practitioners Manual*. Retrieved March 12, 2023, from https://manual.forecast-based-financing.org/en/

IFRC, RCCC, & GRC. (2023b). *FbF Practitioners Manual. Chapter 4.1 Set the Trigger*. Retrieved March 12, 2023, from https://manual.forecast-based-financing.org/en/chapter/set-the-trigger/

IFRC, RCCC, & GRC. (2023c). *FbF Practitioners Manual. Chapter 4.2 Select Early Actions*. Retrieved March 12, 2023, from https://manual.forecast-based-financing.org/en/chapter/select-early-actions/

IFRC, RCCC, & GRC. (2023d). *Glossary of Terms for Forecast-based Financing*. FbF Practitioners Manual. Retrieved March 12, 2023, from https://manual.forecast-based-financing.org/en/chapter/glossary/

Ighalo, J. O., & Adeniyi, A. G. (2020). A comprehensive review of water quality monitoring and assessment in Nigeria. *Chemosphere*, *260*, 127569. https://doi.org/10.1016/j.chemosphere.2020.127569

Inayath, C. M. (2018). EARLY WARNING SYSTEM AND COMMUNITY BASED EMERGENCY RESPONSE MECHANISM, 84.

IPCC. (2012). Glossary of Terms. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA.*, 555–564. https://archive.ipcc.ch/pdf/special-reports/srex/SREX-Annex_Glossary.pdf

IPCC. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. *Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental Panel on Climate Change*, *1132*.

Jarrett, P., Zadravecz, F. J., O'Keefe, J., Nshombo, M., Karume, A., & Roberts, L. (2020). Evaluation of a population mobility, mortality, and birth surveillance system in South Kivu, Democratic Republic of the Congo. *Disasters*, *44*(2), 390–407. https://doi.org/10.1111/disa.12370

Jung, J., Beledi, A. H., Riedel, N., Ahmed, A. O., & Larsen, T. M. (2022). Community Based Surveillance in Somaliland: Analysis of the Functionality and Effectiveness using the CBS Platform Nyss. *International Journal of Infectious Diseases*, *116*, S100. https://doi.org/10.1016/j.ijid.2021.12.236

Keough, H. L., & Blahna, D. J. (2006). Achieving integrative, collaborative ecosystem management. *Conservation Biology: The Journal of the Society for Conservation Biology*, *20*(5), 1373–1382. https://doi.org/10.1111/j.1523-1739.2006.00445.x

Kim, J.-S., Park, S.-Y., Chen, J., Chen, S., Kim, T.-W., & Lee, J.-H. (2021). Integrated Drought Monitoring and Evaluation through Multi-Sensor Satellite-Based Statistical Simulation. *Remote Sensing*, *13*, 272. https://doi.org/10.3390/rs13020272

Kim, S., Robson, C., Zimmerman, T., Pierce, J., & Haber, E. M. (2011). Creek watch: Pairing usefulness and usability for successful citizen science. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2125–2134. https://doi.org/10.1145/1978942.1979251

Kirschke, S., Bennett, C., Bigham Ghazani, A., Franke, C., Kirschke, D., Lee, Y., Loghmani Khouzani, S. T., & Nath, S. (2022). Citizen science projects in freshwater monitoring. From individual design to clusters? *Journal of Environmental Management*, *309*, 114714. https://doi.org/10.1016/j.jenvman.2022.114714

Klobucista, C. (2018). *Somaliland: The Horn of Africas Breakaway State*. Council on Foreign Relations. Retrieved March 21, 2023, from https://www.cfr.org/backgrounder/somaliland-horn-africas-breakaway-state

Koehler, B., & Koontz, T. M. (2008). Citizen Participation in Collaborative Watershed Partnerships. *Environmental Management*, *41*(2), 143–154. https://doi.org/10.1007/s00267-007-9040-z

Kolen, B., Slomp, R., & Jonkman, S. (2013). The impacts of storm Xynthia February 2728, 2010 in France: Lessons for flood risk management. *Journal of Flood Risk Management*, *6*(3), 261–278. https://doi.org/10.1111/jfr3.12011

Kullenberg, C., & Kasperowski, D. (2016). What Is Citizen Science? A Scientometric Meta-Analysis. *PLOS ONE*, *11*(1), e0147152. https://doi.org/10.1371/journal.pone.0147152

Lackstrom, K., Farris, A., & Ward, R. (2022). Backyard Hydroclimatology: Citizen Scientists Contribute to Drought Detection and Monitoring. *Bulletin of the American Meteorological Society*, *-1*. https://doi.org/10.1175/BAMS-D-21-0157.1

Land-Zandstra, A., Agnello, G., & Gültekin, Y. S. (2021). Participants in Citizen Science. In K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, M. Ponti, R. Samson, & K. Wagenknecht (Eds.), *The Science of Citizen Science* (pp. 243–259). Springer International Publishing. https://doi.org/10.1007/978-3-030-58278-4_13

Lawrimore, J. H., Wuertz, D., Wilson, A., Stevens, S., Menne, M., Korzeniewski, B., Palecki, M. A., Leeper, R. D., & Trunk, T. (2020). Quality Control and Processing of Cooperative Observer Program Hourly Precipitation Data. *Journal of Hydrometeorology*, *21*(8), 1811–1825. https://doi.org/10.1175/JHM-D-19-0300.1

Leal Filho, W., Barbir, J., Gwenzi, J., Ayal, D., Simpson, N. P., Adeleke, L., Tilahun, B., Chirisa, I., Gbedemah, S. F., Nzengya, D. M., Sharifi, A., Theodory, T., & Yaffa, S. (2022). The role of indigenous knowledge in climate change adaptation in Africa. *Environmental Science & Policy*, *136*, 250–260. https://doi.org/10.1016/j.envsci.2022.06.004

Leal Filho, W., Totin, E., Franke, J. A., Andrew, S. M., Abubakar, I. R., Azadi, H., Nunn, P. D., Ouweneel, B., Williams, P. A., & Simpson, N. P. (2022). Understanding responses to climate-related water scarcity in Africa. *Science of The Total Environment*, *806*, 150420. https://doi.org/10.1016/j.scitotenv.2021.150420

LeBaron, G., & National Audubon Society. (2022). *The 122nd Christmas Bird Count Summary*. Audubon. Retrieved March 18, 2023, from https://www.audubon.org/news/the-122nd-christmas-bird-count-summary

Link, W. A., Sauer, J. R., & Niven, D. K. (2006). A Hierarchical Model for Regional Analysis of Population Change Using Christmas Bird Count Data, with Application to the American Black Duck. *The Condor*, *108*(1), 13–24. https://doi.org/10.1650/0010-5422(2006)108[0013:AHMFRA]2.0.CO;2

Liu, J., Shen, H., Narman, H. S., Chung, W., & Lin, Z. (2018). A Survey of Mobile Crowdsensing Techniques: A Critical Component for The Internet of Things. *ACM Transactions on Cyber-Physical Systems*, *2*(3), 18:1–18:26. https://doi.org/10.1145/3185504

Liu, J., Yang, H., Gosling, S. N., Kummu, M., Flörke, M., Pfister, S., Hanasaki, N., Wada, Y., Zhang, X., Zheng, C., Alcamo, J., & Oki, T. (2017). Water scarcity assessments in the past, present, and future. *Earth's Future*, *5*(6), 545–559. https://doi.org/10.1002/2016EF000518

Liu, J., & Zhao, D. (2020). Three-dimensional water scarcity assessment by considering water quantity, water quality, and environmental flow requirements: Review and prospect. *Chin. Sci. Bull*, *65*, 4251–4261.

Lopez, C. (2021). Motives for Citizen Science Program Participation and the Role of the Organization: Lessons from Water Quality Monitors in Texas. *Citizen Science: Theory and Practice*, *6*(1), 3. https://doi.org/10.5334/cstp.341

Lowry, C. S., Fienen, M. N., Hall, D. M., & Stepenuck, K. F. (2019). Growing Pains of Crowdsourced Stream Stage Monitoring Using Mobile Phones: The Development of CrowdHydrology. *Frontiers in Earth Science*, *7*. Retrieved October 21, 2022, from https://www.frontiersin.org/articles/10.3389/feart.2019.00128

Macherera, M., & Chimbari, M. J. (2016). A review of studies on community based early warning systems. *Jàmbá : Journal of Disaster Risk Studies*, *8*(1). https://doi.org/10.4102/jamba.v8i1.206

Manalo, D. (2013). Bell and Bottle Technology: Community-based Early Warning System. *Agriculture and Development Notes*, *2*, 1–2. Retrieved September 28, 2022, from https://ideas.repec.org/a/sag/seaadn/2013237.html

Marchezini, V., Horita, F. E. A., Matsuo, P. M., Trajber, R., Trejo-Rangel, M. A., & Olivato, D. (2018). A Review of Studies on Participatory Early Warning Systems (P-EWS): Pathways to Support Citizen Science Initiatives. *Frontiers in Earth Science*, *6*. Retrieved September 28, 2022, from https://www.frontiersin.org/articles/10.3389/feart.2018.00184

Masinde, M. (2014, September 28). *An Effective Drought Early Warning System for Sub- Saharan Africa: Integrating Modern and Indigenous Approaches*. https://doi.org/10.1145/2664591.2664629

Masinde, M., & Bagula, A. (2010). A framework for predicting droughts in developing countries using sensor networks and mobile phones. *Proceedings of the 2010 Annual Research Conference of the South African Institute of Computer Scientists and Information Technologists*, 390–393. https://doi.org/10.1145/1899503.1899551

Masinde, M., & Bagula, A. (2012). ITIKI: Bridge between African indigenous knowledge and modern science of drought prediction. *Knowledge Management for Development Journal*, *7*(3), 274?290–274?290. Retrieved October 25, 2022, from https://www.km4djournal.org/index.php/km4dj/article/view/455

Masinde, M., Bagula, A., & Muthama, N. (2013). Implementation roadmap for downscaling drought forecasts in Mbeere using ITIKI. *2013 Proceedings of ITU Kaleidoscope: Building Sustainable Communities*, 1–8.

Masinde, M., Mwagha, S., & Tadesse, T. (2018). Downscaling Africas Drought Forecasts through Integration of Indigenous and Scientific Drought Forecasts Using Fuzzy Cognitive Maps. *Geosciences*, *8*, 135. https://doi.org/10.3390/geosciences8040135

Masinde, M., & Thothela, P. N. (2019). ITIKI Plus: A Mobile Based Application for Integrating Indigenous Knowledge and Scientific Agro-Climate Decision Support for Africas Small-Scale Farmers. *2019 IEEE 2nd International Conference on Information and Computer Technologies (ICICT)*, 303–309. https://doi.org/10.1109/INFOCT.2019.8711059

McGowan, C. R., Takahashi, E., Romig, L., Bertram, K., Kadir, A., Cummings, R., & Cardinal, L. J. (2022). Community-based surveillance of infectious diseases: A systematic review of drivers of success. *BMJ global health*, *7*(8), e009934. https://doi.org/10.1136/bmjgh-2022-009934

McNeil, C., Verlander, S., Divi, N., & Smolinski, M. (2022). The Landscape of Participatory Surveillance Systems Across the One Health Spectrum: Systematic Review. *JMIR Public Health and Surveillance*, *8*(8), e38551. https://doi.org/10.2196/38551

Metuge, A., Omam, L.-A., Jarman, E., & Njomo, E. O. (2021). Humanitarian led community-based surveillance: Case study in Ekondo-titi, Cameroon. *Conflict and Health*, *15*(1), 17. https://doi.org/10.1186/s13031-021-00354-9

Minkman, E. (2015). Citizen Science in Water Quality Monitoring: Developing Guidelines for Dutch Water Authorities for Contributory Mobile Crowd Sensing. Retrieved October 21, 2022, from https://repository.tudelft.nl/islandora/object/uuid%3A3850a8ec-d6aa-4f7d-a3ae-2f48f53cc148

Mishra, B. K., Kumar, P., Saraswat, C., Chakraborty, S., & Gautam, A. (2021). Water Security in a Changing Environment: Concept, Challenges and Solutions. *Water*, *13*(4), 490. https://doi.org/10.3390/w13040490

Mitlin, D., Beard, V. A., Satterthwaite, D., & Du, J. (n.d.). Unaffordable and Undrinkable:

Mloza-Banda, C., & Scholtz, B. (2018). Crowdsensing for successful water resource monitoring: An analysis of citizens' intentions and motivations. *Proceedings of the Annual Conference of the South African Institute of Computer Scientists and Information Technologists*, 55–64. https://doi.org/10.1145/3278681.3278688

Molden, D., Institute, I. W. M., & of Water Management in Agriculture (Program), C. A. (Eds.). (2007). *Water for food, water for life: A comprehensive assessment of water management in agriculture*. Earthscan.
OCLC: ocm71285428.

Moriarty, P., Butterworth, J., & Batchelor, C. (2004). Integrated Water Resources Management and the Domestic Water and Sanitation Sub-Sector. Thematic Overview Paper. *Netherlands: IRC International Water and Sanitation Centre*.

Muhamad Khair, N. K., Lee, K. E., & Mokhtar, M. (2021). Community-based monitoring for environmental sustainability: A review of characteristics and the synthesis of criteria.

Journal of Environmental Management, *289*, 112491. https://doi.org/10.1016/j.jenvman.2021.112491

Musei, S. K., Nyaga, J. M., & Dubow, A. Z. (2021). SPEI-based spatial and temporal evaluation of drought in Somalia. *Journal of Arid Environments*, *184*, 104296. https://doi.org/10.1016/j.jaridenv.2020.104296

NCAR. (n.d.-a). *Standardized Precipitation Evapotranspiration Index (SPEI)*. Retrieved March 10, 2023, from https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-evapotranspiration-index-spei

NCAR. (n.d.-b). *Standardized Precipitation Index (SPI)*. Retrieved March 10, 2023, from https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-index-spi

NDMC. (2023a). Types of Drought. In *National Drought Mitigation Center*. University of Nebraska-Lincoln. Retrieved March 7, 2023, from https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx

NDMC. (2023b). What is Drought? In *National Drought Mitigation Center*. University of Nebraska-Lincoln. Retrieved March 6, 2023, from https://drought.unl.edu/Education/DroughtIn-depth/WhatisDrought.aspx

NIDIS. (2023). *Outlooks & Forecasts*. Drought.gov. Retrieved March 13, 2023, from https://www.drought.gov/forecasts

Nikolay, B., Salje, H., Sturm-Ramirez, K., Azziz-Baumgartner, E., Homaira, N., Ahmed, M., Iuliano, A. D., Paul, R. C., Rahman, M., Hossain, M. J., Luby, S. P., Cauchemez, S., & Gurley, E. S. (2017). Evaluating Hospital-Based Surveillance for Outbreak Detection in Bangladesh: Analysis of Healthcare Utilization Data. *PLOS Medicine*, *14*(1), e1002218. https://doi.org/10.1371/journal.pmed.1002218

Noureen, J., & Asif, M. (2017). Crowdsensing: Socio-Technical Challenges and Opportunities. *International Journal of Advanced Computer Science and Applications*, *8*(3). https://doi.org/10.14569/IJACSA.2017.080351

NRC. (2023). *Nyss: A tool developed with the Red Cross for Community-Based Surveillance*. Retrieved October 26, 2022, from https://github.com/nyss-platform-norcross/nyss

NRC & IFRC. (2021). NYSS a community-based surveillance platform. User manual.

NRC & IFRC. (2023). *What is Nyss*. Retrieved March 22, 2023, from https://www.cbsrc.org/what-is-nyss

Nyetanyane, J., & Masinde, M. (2020). Integration of Indigenous Knowledge, Climate Data, Satellite Imagery and Machine Learning to Optimize Cropping Decisions by Small-Scale Farmers. a Case Study of uMgungundlovu District Municipality, South Africa. In J. P. R. Thorn, A. Gueye, & A. P. Hejnowicz (Eds.), *Innovations and Interdisciplinary Solutions for Underserved Areas* (pp. 3–19). Springer International Publishing. https://doi.org/10.1007/978-3-030-51051-0_1

Obeng-Odoom, F. (2012). Beyond access to water. *Development in Practice*, *22*(8), 1135–1146. https://doi.org/10.1080/09614524.2012.714744

Observatory, E. D. (2017). Drought Indicators. Retrieved March 10, 2023, from https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1010

OCHA. (2020). ANTICIPATORY ACTION PLAN For Drought in Somalia.

Organization, K. (n.d.). *KoboToolbox*. KoboToolbox. Retrieved March 20, 2023, from https://www.kobotoolbox.org/

Oxfam. (2009). Introduction to Community-Based Water Resource Management: A Learning Companion Oxfam Disaster Risk Reduction and Climate Change Adaptation Resources. https://www.oxfamwash.org/water/cbwrm/Oxfam%20CBWRM%20Companion,%202009.pdf

Palmer, W. C. (1965). *Meteorological Drought*. U.S. Department of Commerce, Weather Bureau.

Peifer, D. C. (2009, May). *Stopping Mass Killings in Africa: Genocide, Airpower, and Intervention*. DIANE Publishing.

Petrucci, B. (2022). Landscape and Landforms of Northern Somalia. In P. Billi (Ed.), *Landscapes and Landforms of the Horn of Africa: Eritrea, Djibouti, Somalia* (pp. 233–247). Springer International Publishing. https://doi.org/10.1007/978-3-031-05487-7_10

Pettibone, L., Vohland, K., Bonn, A., Richter, A., Bauhus, W., Behrisch, B., Borcherding, R., Brandt, M., Bry, F., Dörler, D., Elbertse, I., Glöckler, F., Göbel, C., Hecker, S., Heigl, F., Herdick, M., Kiefer, S., Kluttig, T., Kühn, E., & Ziegler, D. (2016, July 1). *Citizen science for all. A guide for citizen science practitioners*.

Pineda, M. V. G. (2015). Redefining Community Based Disaster Risk Management (CBDRM) through Enhanced Early Warning Processes. *International Journal of Information and Education Technology*, *5*(7), 543–548. https://doi.org/10.7763/IJIET.2015.V5.565

Pocock, M. J. O., Chapman, D. S., Sheppard, L. J., & Roy, H. E. (n.d.). A Strategic Framework to Support the Implementation of Citizen Science for Environmental Monitoring, 67.

Quinn, P., Jasmontaite, L., Barboza, J. Z., Riedel, N., & Larsen, T. M. (2020). *Nyss - DATA PROTECTION IMPACT ASSESSMENT REPORT*. NRC & BRC.

Ratnayake, R., Finger, F., Edmunds, W. J., & Checchi, F. (2020). Early detection of cholera epidemics to support control in fragile states: Estimation of delays and potential epidemic sizes. *BMC Medicine*, *18*(1), 397. https://doi.org/10.1186/s12916-020-01865-7

Ratnayake, R., Tammaro, M., Tiffany, A., Kongelf, A., Polonsky, J. A., & McClelland, A. (2020). People-centred surveillance: A narrative review of community-based surveillance among crisis-affected populations. *The Lancet Planetary Health*, *4*(10), e483–e495. https://doi.org/10.1016/S2542-5196(20)30221-7

RCRC. (2020). *FORECAST-BASED FINANCING AND EARLY ACTION FOR DROUGHT*.

Renn, O. (2006). Participatory processes for designing environmental policies. *Land Use Policy*, *23*(1), 34–43. https://doi.org/10.1016/j.landusepol.2004.08.005

Republic of Somalia. (2021). Republic of Somaliland Country Profile 2021.

Republic of Somaliland. (2019). Regions and Districts Self-management Law, No. 23/2019.

Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., Lewis, D., & Jacobs, D. (2012). Dynamic changes in motivation in collaborative citizen-science projects. *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work*, 217–226. https://doi.org/10.1145/2145204.2145238

Rüth, A., Siahaan, K. D., Coughlan, E., Kelly, T., Jaime, C., Bailey, M., & Lux, S. (2017). Forecast-based financing: A policy overview.

Rutten, M., Minkman, E., & van der Sanden, M. (2017). How to get and keep citizens involved in mobile crowd sensing for water management? A review of key success factors and motivational aspects. *WIREs Water*, *4*(4), e1218. https://doi.org/10.1002/wat2.1218

Sadoff, C., Grey, D., & Borgomeo, E. (2020, May 29). *Water Security*. Oxford Research Encyclopedia of Environmental Science. https://doi.org/10.1093/acrefore/9780199389414.013.609

Salem, U. (2016). *Territorial diagnostic report of the land resources of Somaliland*. FAO-SWALIM. Nairobi, Kenya.

San Llorente Capdevila, A., Kokimova, A., Sinha Ray, S., Avellán, T., Kim, J., & Kirschke, S. (2020). Success factors for citizen science projects in water quality monitoring. *Science of The Total Environment*, *728*, 137843. https://doi.org/10.1016/j.scitotenv.2020.137843

Sauermann, H., & Franzoni, C. (2015). Crowd science user contribution patterns and their implications. *Proceedings of the National Academy of Sciences*, *112*(3), 679–684. https://doi.org/10.1073/pnas.1408907112

SCRS. (2022). *Feasibility Study on Potential Use of Forecast-based Financing (FbF) for SRCS*. Nottawasaga Institute.

Shirk, J., Ballard, H., Wilderman, C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B., Krasny, M., & Bonney, R. (2012). Public Participation in Scientific Research: A Framework for Deliberate Design. *Ecology and Society*, *17*(2). https://doi.org/10.5751/ES-04705-170229

Siahaan, K. D. (2018). Forecast-based Action by the DREF. https://www.forecast-based-financing.org/wp-content/uploads/2018/10/DRK_Broschuere_FUND_Web_ENG.pdf

Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution*, *24*(9), 467–471. https://doi.org/10.1016/j.tree.2009.03.017

Skarlatidou, A., Hamilton, A., Vitos, M., & Haklay, M. (2019). What do volunteers want from citizen science technologies? A systematic literature review and best practice guidelines. *JCOM: Journal of Science Communication*, *18*(1). Retrieved November 11, 2022, from https://doi.org/10.22323/2.18010202

Smith, P. J., Brown, S., & Dugar, S. (2017). Community-based early warning systems for flood risk mitigation in Nepal. *Natural Hazards and Earth System Sciences*, *17*(3), 423–437. https://doi.org/10.5194/nhess-17-423-2017

Society, L. R. C., & IFRC. (2022). EARLY ACTION PROTOCOL SUMMARY Lesotho Drought EAP.

Society, N. R. C., & IFRC. (2021). Niger: Drought Early Action Protocol summary.

Speir, S. L., Shang, L., Bolster, D., Tank, J. L., Stoffel, C. J., Wood, D. M., Peters, B. W., Wei, N., & Wang, D. (2022). Solutions to Current Challenges in Widespread Monitoring of Groundwater Quality via Crowdsensing. *Groundwater*, *60*(1), 15–24. https://doi.org/10.1111/gwat.13150

SRCS. (2021). *DRM Strategic Plan final*. Google Docs. Retrieved February 18, 2023, from https://drive.google.com/file/d/17E7ZwAsWHYaxfMPzD9WZK9n6yYsH5L2j/view?usp=embed_facebook

Srivastava, S., Vaddadi, S., & Sadistap, S. (2018). Smartphone-based System for water quality analysis. *Applied Water Science*, *8*. https://doi.org/10.1007/s13201-018-0780-0

Starkey, E., Parkin, G., Birkinshaw, S., Large, A., Quinn, P., & Gibson, C. (2017). Demonstrating the value of community-based (citizen science) observations for catchment modelling and characterisation. *Journal of Hydrology*, *548*, 801–817. https://doi.org/10.1016/j.jhydrol.2017.03.019

Stephens, E., Coughlan de Perez, E., Kruczkiewicz, A., Boyd, E., & Suarez, P. (2015). FORECASTBASED ACTION.

Sullivan, C., Meigh, J., & Giacomello, A. (2003). The Water Poverty Index: Development and application at the community scale. *Natural Resources Forum*, *27*(3), 189–199. https://doi.org/10.1111/1477-8947.00054

Svoboda, M., Fuchs, B., & IDMP. (2016). Handbook of Drought Indicators and Indices.

Swanson, W., Walters, L., Wilton, P., & Nyakairu, F. (2022, December 13). *Nearly 8.3 million people across Somalia face Crisis (IPC Phase 3) or worse acute food insecurity outcomes*. OCHA. Retrieved March 21, 2023, from https://reliefweb.int/report/somalia/nearly-83-million-people-across-somalia-face-crisis-ipc-phase-3-or-worse-acute-food-insecurity-outcomes

Tarchiani, V., Massazza, G., Rosso, M., Tiepolo, M., Pezzoli, A., Housseini Ibrahim, M., Katiellou, G. L., Tamagnone, P., De Filippis, T., Rocchi, L., Marchi, V., & Rapisardi, E. (2020). Community and Impact Based Early Warning System for Flood Risk Preparedness: The Experience of the Sirba River in Niger. *Sustainability*, *12*(5), 1802. https://doi.org/10.3390/su12051802

Tariq, M. O., Siddiq, A., Irshad, H., Aman, M., & Khan, M. S. (2021). An Open Source Water Quality Measurement System for Remote Areas. *Engineering Proceedings*, *12*(1), 50. https://doi.org/10.3390/engproc2021012050

Technical Contributors to the June 2018 WHO meeting. (2019). A definition for community-based surveillance and a way forward: Results of the WHO global technical meeting, France, 26 to 28 June 2018. *Euro Surveillance: Bulletin Europeen Sur Les Maladies Transmissibles = European Communicable Disease Bulletin*, *24*(2), 1800681. https://doi.org/10.2807/1560-7917.ES.2019.24.2.1800681

Thothela, P., Markus, E., Masinde, M., & Abu-Mahfouz, A. (2021, January 1). A Survey of Intelligent Agro-climate Decision Support Tool for Small-Scale Farmers: An Integration of Indigenous Knowledge, Mobile Phone Technology and Smart Sensors. https://doi.org/10.1007/978-981-15-8354-4_71

Tipaldo, G., & Allamano, P. (2017). Citizen science and community-based rain monitoring initiatives: An interdisciplinary approach across sociology and water science. *WIREs Water*, *4*(2), e1200. https://doi.org/10.1002/wat2.1200

Trisos, C., Adelekan, I., Totin, E., Christopher, T., Ayanlade, S., Efitre, J., Adugna, G., Kalaba, F., Lennard, C., Catherine, M., Mgaya, Y., Grace, N., Daniel, O., Sumaya, Z., & Simpson, N. (2022, December 31). Africa. In H.-O. Pörtner, D.C. Roberts, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the*

Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1285–145). Cambridge University Press, Cambridge, UK and New York, NY, USA. doi:10.1017/9781009325844.011

Trogrli, R., & van den Homberg, M. (2018, September 17). *Indigenous knowledge and early warning systems in the Lower Shire Valley in Malawi*.

UNDRR. (2015). Sendai Framework for Disaster Risk Reduction 2015 - 2030.

UNDRR. (2021). *Special report on drought 2021*. United Nations.

UNISDR. (2005). Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters.

UNISDR. (2009). UNISDR terminology on disaster risk reduction. *Geneva: United Nations*.

United Nations. (2002). *Deepening democracy in a fragmented world*. Oxford Univ. Press.

United Nations University. (2017). Too Many Indicators and Indices Make Monitoring Water Quality a Murky Business. Retrieved March 10, 2023, from https://flores.unu.edu/en/news/news/too-many-indicators-and-indices-make-monitoring-water-quality-a-murky-business.html#info

USAID. (2018). Economics of Resilience to Drought: Somalia Analysis.

Ushahidi. (n.d.). *Crowdsourcing Solutions to Empower Communities*. Ushahidi. Retrieved March 20, 2023, from https://www.ushahidi.com//

Van Beek, E., & Arriens, W. L. (2014). *Water security: Putting the concept into practice*. Global Water Partnership Stockholm.

Van Loon, A. F., Stahl, K., Di Baldassarre, G., Clark, J., Rangecroft, S., Wanders, N., Gleeson, T., Van Dijk, A. I. J. M., Tallaksen, L. M., Hannaford, J., Uijlenhoet, R., Teuling, A. J., Hannah, D. M., Sheffield, J., Svoboda, M., Verbeiren, B., Wagener, T., & Van Lanen, H. A. J. (2016). Drought in a human-modified world: Reframing drought definitions, understanding, and analysis approaches. *Hydrology and Earth System Sciences*, *20*(9), 3631–3650. https://doi.org/10.5194/hess-20-3631-2016

Vhumbunu, C. H. (2021). Counting Down to Day Zero: Exploring Community-Based Water Management Strategies in Western Cape Province Drought, South Africa (2017/2018). In R. Djalante, M. B. F. Bisri, & R. Shaw (Eds.), *Integrated Research on Disaster Risks: Contributions from the IRDR Young Scientists Programme* (pp. 193–212). Springer International Publishing. https://doi.org/10.1007/978-3-030-55563-4_11

Walker, D. W., Smigaj, M., & Tani, M. (2021). The benefits and negative impacts of citizen science applications to water as experienced by participants and communities. *WIREs Water*, *8*(1), e1488. https://doi.org/10.1002/wat2.1488

Walker, R., & Sugule. (1998). Changing Pastoralism in the Ethiopian Somali National Regional State (Region 5). Retrieved December 14, 2022, from https://www.africa.upenn.edu/Hornet/past0698.html

Wang, H. (2022). A Survey of Application and Key Techniques for Mobile Crowdsensing. *Wireless Communications and Mobile Computing*, *2022*, e3693537. https://doi.org/10.1155/2022/3693537

Wang, W., Ertsen, M. W., Svoboda, M. D., & Hafeez, M. (2016). Propagation of Drought: From Meteorological Drought to Agricultural and Hydrological Drought. *Advances in Meteorology*, *2016*, e6547209. https://doi.org/10.1155/2016/6547209

Weeser, B., Stenfert Kroese, J., Jacobs, S. R., Njue, N., Kemboi, Z., Ran, A., Rufino, M. C., & Breuer, L. (2018). Citizen science pioneers in Kenya A crowdsourced approach for hydrological monitoring. *Science of The Total Environment*, *631–632*, 1590–1599. https://doi.org/10.1016/j.scitotenv.2018.03.130

WEF. (2009). The bubble is close to bursting: A forecast of the main economic and geopolitical water issues likely to arise in the world during the next two decades. *World Economic Forum.< http://www. Weforum. Org/Pdf/Water/WaterInitiativeFutureWaterNeeds. Pdf>(Accessed 09.03. 10)*.

Weston, S., & Conrad, C. (2015). Community-Based Water Monitoring in Nova Scotia: Solutions for Sustainable Watershed Management. *Environment and Natural Resources Research*, *5*(2), p1. https://doi.org/10.5539/enrr.v5n2p1

WFP, Gros, C., Kazis, P., & Mason, J. (2021). Monitoring and evaluation of anticipatory actions for drought: Guidance and tools for Forecast-based Financing programmes.

Whitelaw, G., Vaughan, H., Craig, B., & Atkinson, D. (2003). Establishing the Canadian Community Monitoring Network. *Environmental Monitoring and Assessment*, *88*(1), 409–418. https://doi.org/10.1023/A:1025545813057

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

Williams, M., & Eggleston, S. (2017, October 13). Using indicators to explain our changing climate to policymakers and the public. Retrieved March 10, 2023, from https://public.wmo.int/en/resources/bulletin/using-indicators-explain-our-changing-climate-policymakers-and-public

Wilson-Jones, T., & Rivett, U. (2012). Using Mobile Phones to Monitor and Manage Water Supply Quality in Rural Environments. *WISA 2012 Biennial Conference and Exhibition*.

WMO (Ed.). (2013). *Planning of water-quality monitoring systems*. World Meteorological Organization.

World Bank. (1997). *World Development Report 1997: The State in a Changing World.* New York: Oxford University Press. https://doi.org/10.1596/978-0-1952-1114-6

World Bank. (2014). *New World Bank GDP and Poverty Estimates for Somaliland*. World Bank. Retrieved March 21, 2023, from https://www.worldbank.org/en/news/press-release/2014/01/29/new-world-bank-gdp-and-poverty-estimates-for-somaliland

World Bank. (2016). *High and Dry: Climate Change, Water, and the Economy*. World Bank. Washington, DC. Retrieved March 8, 2023, from https://www.worldbank.org/en/topic/water/publication/high-and-dry-climate-change-water-and-the-economy

World Bank. (n.d.). *Global Risk Financing Facility*. World Bank. Retrieved March 9, 2023, from https://www.worldbank.org/en/topic/disasterriskmanagement/brief/global-risk-financing-facility

Yuan, Y., Yang, H., Zhou, W., & Li, C. (2008). Influences of the Indian Ocean dipole on the Asian summer monsoon in the following year. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *28*(14), 1849–1859.

Zamxaka, M., Pironcheva, G., & Muyima, N. Y. O. (2004). Microbiological and physico-chemical assessment of the quality of domestic water sources in selected rural communities of the Eastern Cape Province, South Africa. *Water SA*, *30*(3), 333–340. https://doi.org/10.4314/wsa.v30i3.5081

Zheng, F., Tao, R., Maier, H. R., See, L., Savic, D., Zhang, T., Chen, Q., Assumpção, T. H., Yang, P., Heidari, B., Rieckermann, J., Minsker, B., Bi, W., Cai, X., Solomatine, D., & Popescu, I. (2018). Crowdsourcing Methods for Data Collection in Geophysics: State of the Art, Issues, and Future Directions. *Reviews of Geophysics*, *56*(4), 698–740. https://doi.org/10.1029/2018RG000616