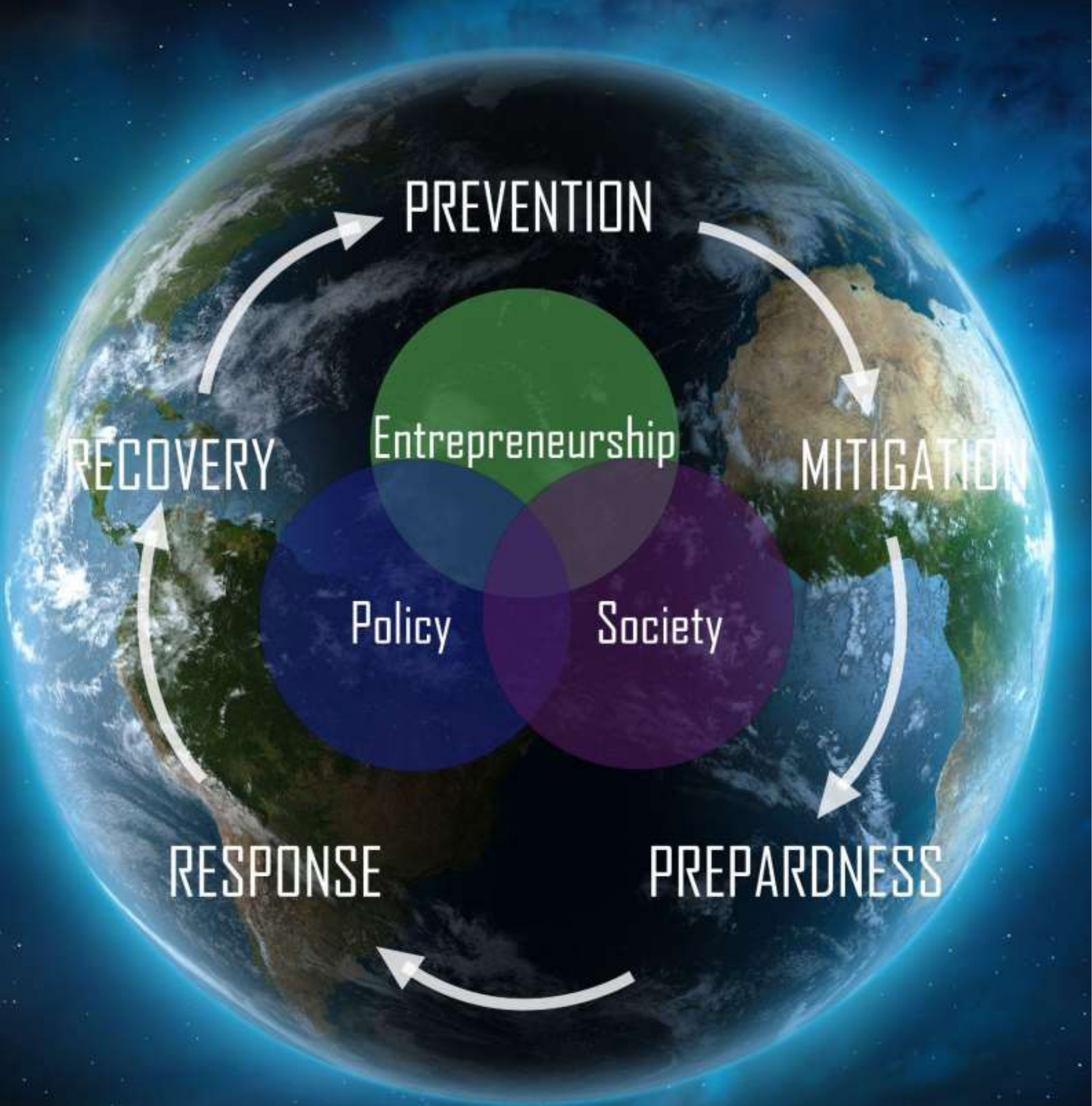
INNOVATION FOR CLIMATE RESILIENCE

Towards Societal Adaptation & Sustainable Transformations with BEST PRACTICE Solutions in Flood Risk Management & Governance



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Innovation for Climate Resilience: Towards Societal Adaptation and Sustainable Transformations with Best Practice Solutions in Flood Risk Management and Governance

Technological change and innovation are increasingly seen as being able to provide solutions to addressing flood risks and fatalities caused by accelerating climate change. Yet, associated stakeholders face divergent challenges: 1) Stakeholders tend to act in isolation creating silos in flood risk management and governance; 2) Public sector is challenged in moving forward with flood prevention and single-purpose solutions; 3) Citizens are still waiting to be connected to the flood risk management domain and facilitated to contribute; and 4) Entrepreneurs with potentially useful ideas need experimenting with the possibility of multiple value creation that stems from multi-stakeholder collaborations.

To update stakeholders on new technologies which could alleviate the aforementioned challenges and transcend stakeholders' limitations, this research brings forward multiple best practices of technological developments or innovations introduced by public, private and social sector across five stages of disaster risk management of the Sendai Framework: Prevention, Mitigation, Preparedness, Response and Recovery.

Case studies for the social and public sector were identified through a systematic literature review. Surveys with each set of key stakeholders were conducted to better inform the literature review and help select appropriate practices for each stakeholder-stage combination. Foundation for the case studies on the private sector stakeholder group is laid by a systematic search of relevant keywords in news media and grey literature. With three-dimensional selection criteria for each stakeholder, the socio-technological solutions were selected. For the private sector: the most innovative, impactful and profitable technologies (developed or employed). For the public sector: the most cost-effective, feasible and equitable solutions were chosen. And finally, for the social sector the criteria a proven model with the following criteria was employed for selection: Communication, Coordination and Cooperation.

Interviewed stakeholders involved in the public, social and private sector uncovered the following: even though these cases are best practices with respect to the 3-dimensional criteria, there are still multiple barriers in place for their effective and efficient implementation. An overly differentiated and siloed modus operandi towards flood risk management and governance challenges experimenting with developing mutual trust and understanding of each stakeholders' priorities and abilities. Although the public sector increasingly prioritises technology that can bridge the communication gaps between citizens and technical expertise, many start-ups struggle to access sufficient funding to fully pilot test emerging or scale-up proven technologies. Managing stakeholders' expectations of each other and using dialogue platforms to surpass current barriers is deemed as paramount in ensuring effective and efficient use of combined capacities and capabilities. Stakeholder inclusivity and accelerated collaboration through data, digitalisation and transparency allow all relevant stakeholders to utilise technological change and innovation as a leverage to achieve positive returns on flood risk management and governance to enhance potential outcomes for all.

Keywords:

Technology, Best-practice, Flood-risk Management, Multi-stakeholder Collaboration, Multiple Value Creation, Challenges and Opportunities, Climate Adaption, Sustainable Technology Solutions

Introduction

In an era of climate change, adaptation to the increased risk of disasters is essential in achieving the development outcomes as prescribed in the Sustainable Development Goals by 2030 (United Nations General Assembly [UNGA], n.d.). The Sendai Framework marked a key change in the approach to disaster-risk management [DRM] globally, advocating the need for bottom-up management and multi-stakeholder integration (United Nations Office for Disaster Risk Reduction [UNDRR], 2015). Floods are among the disasters which affect the largest number of people worldwide and continue to deteriorate due to increased urbanisation and worsening climate globally (Centre for Research on the Epidemiology of Disasters [CRED], 2019). While there have been many tried and tested technologies and diverse stakeholders with a myriad of technical and non-technical capacities, there is a lack of knowledge of the potential of these technologies in managing floods leading to chronic underinvestment from multiple stakeholders.

First, start-ups aiming at multiple-value creation are often hampered by additional complexities beyond financial constraints. This seems to be particularly true for areas in flood-risk management, given their risk-prone nature. Social and environmental entrepreneurs perceive institutional challenges, including financial resources or administrative burdens, to be higher than normal entrepreneurs (Hoogendorn et al., 2019). Furthermore, students often disregard social entrepreneurial opportunities due to multiple factors, one of which being lacking knowledge about profitable opportunities (Titko et al., 2022). Finally, SMEs and entrepreneurs, in general, face regulatory obstacles, administrative burdens and difficulties with digitalisation, which could be related to a lack of technological innovation in risk-prone sectors like flood management (EC, 2020).

Second, many governments often have poorly designed policies, are unable to follow through on implementation or lack comprehensive strategies altogether. Third, citizens are often brought into disasters during the response phase or entirely excluded as stakeholders with agency, instead being deemed as only victims. Thus, there is often a lack of dialogue, coordination and inclusion of the perspectives of all these actors to better tackle flood risk.

Hence, there is preliminary agreement between previous research that there is a need for bottom-up driven disaster management: "For future dialogues, additional focus should be on identifying best practices related to using state-of-the-art technology to enable efficient governance for DRM" (Oo et al., 2020). In the same vein, this research aims to highlight best practices relevant to the manifold stakeholders involved in flood-risk management. It intends to further provide an overview of the current challenges faced by these stakeholders as well as summarise their expectations and underscore future outlooks of the sector as a whole. The scope of this research is intentionally kept at a broadly international level to ensure its applicability and utility to the maximum number of actors as possible and to avoid a myopic regional/Euro-American focus. This also allows for multiple possible directions for future research.

Conduct of the project/ Research Process

This research project is conducted in the realm of a university-wide undergraduate research excellence programme. The project under which we conduct our research is Innovation for Climate Resilience and our particular research is the first of several semester-long research projects under the supervision of senior researchers from the United Nations University in Maastricht. We, therefore, aimed to lay a sound foundation by developing an appropriate methodology for reviewing current and innovative technologies. We developed and conducted a qualitative meta-synthesis (adopted to social science research). This qualitative meta-synthesis was complemented by surveys to better manage the vast amount of relevant case studies. The second step in this foundation project was to point out barriers and expectations of key stakeholders within and beyond the identified best practices. The insights identified from a thematic analysis of semi-structured interviews will a) point out relevant topics for subsequent research projects and b) be synthesised within this current project to present meaningful conclusions to relevant stakeholders.

Expected Use of Results

The purpose and use of this report is twofold; First, it provides concrete use to the three key stakeholders identified. For the policy and social sector, it highlights best practices which could be replicated or adapted to local contexts globally for enhanced flood-risk management. The best practices identified in the private sector aim at showing that technologies for flood management can be turned into viable businesses. They also show the challenges of prior projects and how they were overcome. The entrepreneurship case studies furthermore point out the costs for adoption and possibilities for scaling as well as meaningful investors or collaborations.

Similarly, all best practices include barriers and expectations which were informed by interviews. These go beyond the current literature to point out possibilities for improvement that stakeholders who aim to adopt the best practices can take into account and possibly take as a first step to improvement. The report also acts as a base for future research processes as described in the respective section. Finally, the report includes an extensive discussion section that brings the insights of the meta-synthesis and the key themes identified in the interviews together to already point to solutions of how to manage barriers and expectations among stakeholders. This section points out challenges and expectations with emerging solutions.

The research project should allow actors within and beyond academia to gain an insight into the general complexities of technologies for flood-risk management which they can extrapolate/contextualise to their purpose.

Conceptual Framework (1-5) including a Technological Review (2) & Methodology (6)

The purpose of this section is manifold from providing contextual background and an introduction into the field, to clarifying this report´s underlying assumptions with the end goal of identifying a review question. This is achieved by conducting a theoretical reflection of relevant concepts employing a review of relevant literature.

The first section of the conceptual frameworks determines key concepts to lay a base of understanding. These clarifications range from a basic definition of Disasters (1.1.) over using the concept of resilience as a meta-criterion (1.4.) to defining stakeholders and their abilities and interests.

The second section will explain why this review employs technology as a Lens. This section entails a brief, yet recent outlook of technologies as discussed in academic literature and the disaster sector from an industry perspective. This shall ensure a holistic foundation for a review of technologies in the public, private and social sector.

The third section argues for the usage of best-practices to achieve the goals of this research.

The fourth section explains why flood disasters were chosen as the focal point of the socio-technological solutions review.

The first four sections lead to conclude with a Review Question which will then inform the Methodology.

The Methodology is the last section which explains in-depth the research process and methods employed to ensure transparency and create replicability of this report´s findings.

1. Definition of key concepts

1.1. Disasters

The United Nations Office for Disaster Risk Reduction (UNDRR) defines a disaster as a “serious disruption to a community or society” caused by “hazardous events interacting with conditions of exposure, vulnerability and capacity.” Disasters have human, material, economic and environmental impacts. Defining key terms is crucial in gaining a proper understanding of the above definition. Disasters can be further categorised according to various typologies. The Sendai Framework categorises disasters based on their scale. This includes the magnitude, frequency, and speed of onset (UNDRR, n.d.). Disasters can also be categorised depending on whether they are natural (such as earthquakes) or man-made (factory accident). This causal analysis however could be debatable depending on the disaster in question (Sawalha, 2020).

1.2. Vulnerability & Hazard

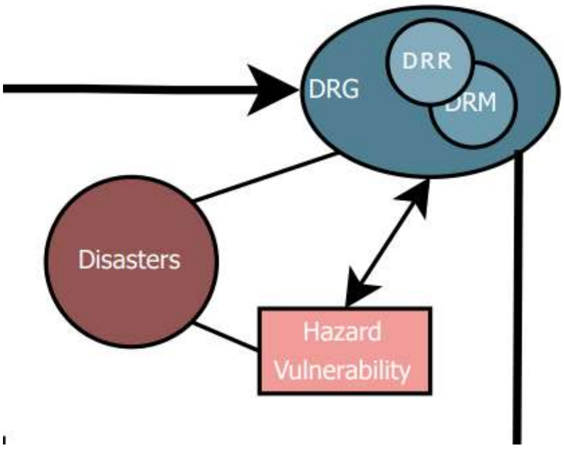
Given the definition of disaster, it is crucial to clarify the definition of the words hazard and vulnerability as they can be used interchangeably. A hazard refers to a phenomenon/activity which leads to the loss of human life, injuries and negatively impacts health, property, the economy, and the environment. Hazards can originate from natural, anthropogenic or a combination of both causes. However, anthropogenic hazards only include human activities and choices which lead to hazards rather than the risk of social conflict. A socio-natural hazard is one which has both natural and anthropogenic causes. Vulnerability on the other hand is defined by the extent to which an individual/community is susceptible to damage by hazards. These are determined/influenced by underlying social, environmental, economic, and physical factors/processes. Thus, a clear distinction between the underlying risks/causes and the potential to impact is seen.

Hazards are defined by their potential to impact a given individual/community while vulnerabilities actually determine the extent to which a hazard impacts the individual/community in question when it occurs. Taking the above definitions and distinction into account it appeas that disaster risk is a product of hazards interacting with vulnerabilities (UNDRR, n.d.). Differentiating between the definitions of hazard and vulnerability would be useful to our research. This distinguishing will allow us to look at whether technology addresses underlying hazards by eliminating them or if they reduce vulnerabilities. To exemplify, new building reinforcements could address the vulnerability of structures to earthquakes, however it cannot address the underlying risk of an earthquake.

1.3. Disaster Risk Terminologies

For addressing disasters as well as the underlying causes which have been identified as hazards and vulnerabilities, three common terms appear to be used interchangeably in both academic and non-academic circles: Disaster Risk Management (DRM) vs Disaster Risk Reduction (DRR) vs Disaster Risk Governance (DRG).

Despite their interchangeable usage, they have different denotations. DRR involves simultaneously reducing existing risk and preventing future, new disaster risks. It further entails managing residual risks that remain after DRR activities take place. DRG entails the systems in place to conduct DRR. This includes mechanisms, policies, legal means, institutions, and networks which guide, manage and coordinate DRR initiatives. Therefore, DRR could be thought of as an objective and DRG as the means to achieve DRR. DRM, however, has a narrower definition which is related to the aforementioned DRR and DRG. DRM is defined as the implementation of policies and strategies to achieve DRR. DRM is broadly classified as either prospective, corrective, or compensatory. Prospective DRM focus on preventing the emergence of future disaster risks or the exacerbation of existing risks. Planning-based solutions take dominance in this type of DRM. Corrective DRM involves reducing or eliminating current disaster risks and usually entails retrofitted solutions. Compensatory DRM pertains to socio-economic resilience given residual risk which cannot be reduced. The nature of solutions includes the establishment and strengthening of socio-economic safety nets and investing in preparedness, response and recovery. Thus, it can be observed that DRM is the process through which the system of institutions and individuals involved in DRG attain a certain level of DRR (UNDRR, n.d.). Thus, it is attempted to govern the risk in order to reduce it by managing these risks and hazards. Therefore, through this review, management processes should be highlighted (specific strategies) from a governance perspective (general system/context)



[***Figure 1****: Extracted part of originally created Conceptual Framework (Illustration of Disaster Terminology and Concepts) of researchers of this report*]

1.4. Resilience

Now that it is clarified what disaster is and different ways of coping with it, a new question to address is: how can the outcomes of DRM processes be evaluated? Is there a single measure that can be utilised? The term resilience was ubiquitous in DRM literature. This prompted our investigation into the use and interpretation of resilience. Therefore, this report conducted a brief review of the term resilience, its heterogeneous interpretations due to its wide use in academia as well as in the Sendai framework. Thus, the researchers conclude that resilience is an appropriate meta-criterion for our best-practice criteria framework.

The UNDRR (n.d.) defines resilience as “the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.” However, the use of the word resilience varies in nature and involves varied connotations depending on its use. Investigating and clarifying this concept would facilitate proper direction in our research.

One lens through which resilience is viewed is by associating it with another concept or by focusing its relevance to a specific theme. The use of resilience along with ‘social’, ‘urban’, ‘organisational’, ‘financial’ or ‘community’ is observable in both academic and non-academic publications. What resilience entails appears to vary depending on which kind of resilience one focuses on. Similarly, the nature of the concept of resilience also gradually changes over time.

Urban resilience was previously associated with ‘bouncing back’ to the same stable state post-disaster known as the conservative approach. However, recent publications and scholarly discussions increasingly embraced the idea of ‘bouncing forward’ to a new stable state post-disaster which is termed as the transformative approach. The rising salience of the transformative approach coincides with that of climate change and adaptation (Chelleri & Baravikova, 2021). The conceptual ambiguity of resilience allows for the integration of diverse stakeholders around a common goal but hampers the measurability of the outcome. “Urban resilience refers to the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity” (Meerow et al., 2016, pp. 45). The above definition broadly incorporates various conceptions of urban resilience which vary regarding their notions of equilibria, adaptation, spatial scale (cities, socio-economic networks) and temporal scale (time periods). The definition of urban resilience continues to evolve as scholarly interest grows (Meerow et al., 2016).

The concept of resilience in terms of a community has gained academic interest over the past two decades. A community is broadly defined as a set of individuals with a common uniting factor. This common factor could be location, ethnicity, employment, or income levels. Furthermore, community resilience is not considered as the sum of its individual members’ resilience but instead a product of individual and organisational resilience (Fan & Lyu, 2021). A generic definition states that it is the ability of a community to mitigate, withstand and recover from a given disaster. This involves both existing disaster risk as well as future possible risks. (Saja et al., 2021). However, the exact definitions and factors that contribute to community resilience vary depending on the perspective it is viewed from. For example, public health perspectives focus on network and health infrastructure adaptability while from a sustainability standpoint the focus is on the development of community resources in a context of uncertainty. Bibliometric analysis shows that community resilience is often used in the context of DRM. Current conceptions of community resilience include an organisational point of view with a focus on strategic awareness as well as the role of resources and capacities in their contribution to resilience (Fan & Lyu, 2021). There is no “one size fits all” conception of community resilience reflecting its contextuality (Keating et al., 2017)

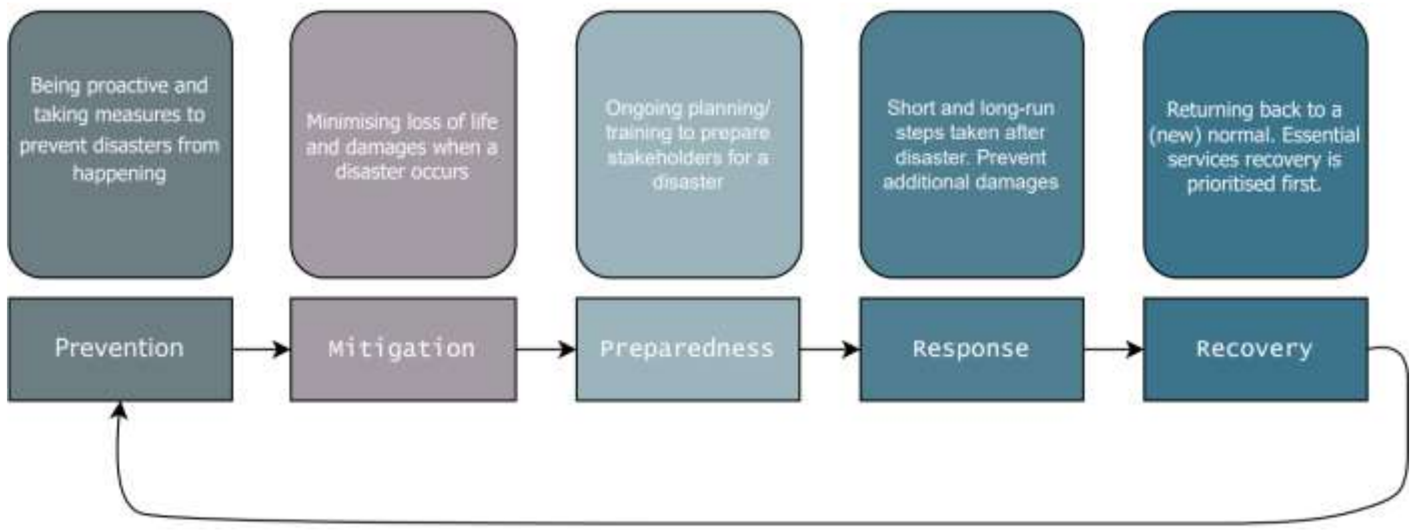
The concept of resilience appears to take various forms and often involves a circular logic where the term to be defined is also part of the definition. To elucidate, the conception of community resilience as proposed by Fan & Lyu (2021) also makes use of organisational and cultural resilience as a component that contributes to community resilience. The various forms of resilience in relation to DRM and its diverse application reflect its multidisciplinary nature. Thus the idea’s conceptual cloudiness and versatile applicability is observable. Given these factors various definitions of resilience tend to portray it as an objective, a means to an objective or an underlying causal factor, indicating a lack of conceptual precision. As highlighted previously the use of circular reasoning is also prevalent. The interdisciplinary/multidisciplinary nature of the concept may also result in contradictory definitions. Finally, the context to which the idea of resilience is applied also significantly influences what resilience actually entails. While they may be viewed as theoretical setbacks, the versatile applicability of resilience as a concept allows it to capture both the tangible, physical facets of a technology as well as the intangible, socio-institutional aspects of its application in DRM. One possible framework with which to view resilience is to base it on context and application. Scale, chronological and societal factors contribute to the context in which resilience is defined. The perspective through which it is applied are either structural (physical), institutional or socio-political. Finally, the mode through which resilience’s application operates include physical properties, systemic properties or governmental processes (MacAskill & Guthrie, 2014).

Keating et al. (2017), propose a possible framework to measure resilience using five forms of capital (5Cs) and four characteristics (4R). Capital is classified as five forms, namely: physical, social, human, natural and financial. Financial capital refers to the diversity of income courses and access to financial resources. Natural capital is essentially the natural resources available in a given place. Physical capital refers to infrastructure and availability of physical equipment in the event of a disaster. Human capital refers to the skills, education, and health of all individuals in a given place/community. Social capital refers to the networks and integration of ideas/resources within a given community and their level of institutionalisation. The establishment and maintenance of all these five forms of capital contribute to resilience against disasters. The qualities these capitals must fulfil are further defined through the use of 4Rs, which are as follows: redundancy, resourcefulness, rapidity and robustness. Redundancy entails the extent to which alternative systems and mechanisms exist to fulfil a given objective/function before, during or after a disaster/shock. Resourcefulness includes the ability to use available resources to both identify problems/risks and take necessary actions to prevent, mitigate or recover. Rapidity is defined by the capacity with which objectives are met and functions restored in a timely manner to minimise damage. Robustness refers to the ability of a system to withstand shocks and damage without compromising its function and outcomes (Keating et al., 2017).

Drawing from the above discussion, the complexity, heterogeneity and contextuality of resilience as a concept can be observed. However, there are some red threads/commonalities that are noticeable. Firstly, the idea of either bouncing back or bouncing forward is connotated in resilience's various definitions. This would link with the response and recovery phases of the DRM cycle that will be discussed in the subsequent section. Secondly the nature of resilience is latent as its true magnitude remains unknown until a disaster strikes. This of course, makes it a complex qualitative aspect to measure with respect to the DRM, however, would be highly useful (Keating et al., 2017). Thirdly there appears to be a binary between ex-ante and ex-post perspectives of resilience. While this may appear to be a source of conceptual tension, newer definitions and frameworks are able to acknowledge and integrate both perspectives into a comprehensive definition of resilience (Keating et al., 2017; UNDRR, n.d.). While the framework proposed by Keating et al. (2017) is highly comprehensive and significantly clarifies the concept of resilience, it is too complex to be used for the purposes of this research paper. It is, however, a useful tool to assess DRM at a local/case study level. Therefore, for the purposes of this report the definition as provided by the UNDRR (n.d.) is used which retains useful qualities defining resilience from the framework developed by Keating et al. (2017). The Intergovernmental Panel on Climate Change (IPCC) defines resilience as follows: "*Resilience in the literature has a wide range of meanings. Adaptation is often organised around resilience as bouncing back and returning to a previous state after a disturbance. More broadly the term describes not just the ability to maintain essential function, identity and structure, but also the capacity for transformation*" (IPCC, 2022b, p.9). While acknowledging the heterogeneity of the definitions of resilience, it is similar to the definition used by UNDRR (n.d.), indicating the validity of these definitions. Therefore, resilience will act as a meta-criterion linking the various aspects of our study and as the central measure to determine best practices.

1.3 Disaster Management Cycle Definition

There is substantial literature about disaster management and models regarding DRM (Oh & Lee, 2020; Novajan et al., 2018). Understanding the classification of disasters is a useful starting point. There are man-made and natural disasters. Man-made disasters refer to socio-technical and warfare disasters such as wars, factory/plant failures and transport failures. Natural disasters refer to those from natural causes and broadly are classified under hydro-meteorological (floods), geo-physical (earthquakes) and biological (pandemics) (Sawalha, 2020). As disasters come in various shapes and sizes, a generic framework for DRM could be epistemologically useful. Various models have been proposed but a cyclical conception of DRM is often referred to in the Sendai framework. This includes a focus on preparedness, response and "building back better." The latter stage entails reconstruction and recovery processes which implicitly lead to a state of resilient preparedness (UNDRR, 2015). As such, the DRM cycle as proposed by University of Central Florida (n.d.) appears to fit this approach to disaster management.



[***Figure 2****: Disaster Risk Management Cycle adopted from UCF (n.d.)*]

While versions of this model are widely used, there are still some criticisms. Multiple standards for disaster management/mitigation exist such as the ISO and BSI. Despite the frameworks accounting for the role of the public, this rarely plays out on ground and dependence on first responders remains high, creating a culture of reliance (Sawalha, 2020).

The existing standards are not sufficiently translated into locally applicable/relevant protocols. Existing protocols remain highly segmented, targeting only specific groups leading to a false sense of security (Sawalha, 2020). This criticism does not target the model's premise but rather its application and translation to daily life. Our research may provide possible case studies where DRM has been successfully translated to protocols.

The design of existing protocols is often flawed as ground-level people follow protocols crafted by management who do not directly face disaster risks. This could lead to errors caused by a lack of insight. Protocols and cycles may be generic but do not emphasise the need for flexibility across various levels to be effective. Disaster management tends to work in a top-down fashion. This often limits its flexibility and adaptability to local context. There appears to be a need for a paradigm that can handle both top-down interests and bottom-up feedback/implementation (Sawalha, 2020). This is a criticism that is accounted for by the Sendai framework which emphasises the importance of stakeholder engagement as well as ensuring DRM from local to transnational scales (UNDRR, 2015).

Accounting for the above criticisms, alternatives have been proposed. The model in Figure 3 focuses on the explicit application of entrepreneurial skills, leadership and innovation into the traditional DRM cycle to gain new managerial insight in the mitigation and response phases. There is also emphasis on the concept of resilience: both biological [survival/mortality] as well as psychological [ability to prosper/recover]. In conjunction with the Sendai framework, this new model proposes distinct levels of resilience from an implementation point of view: community level, organisational level and industrial levels to be integrated into the response and recovery phases of the cycle. However, the preservation of the cyclical conception can be observed as well (Sawalha, 2020). However, this cycle is not significantly different from what is proposed by UCF (n.d.). However it does provide some further nuance by outlining the possible mechanics of a DRM cycle by explicitly mentioning technologie such as early warning systems or highlighting qualities required of a technology such as improving situational awareness. Thus, it becomes a useful supplement to provide a more nuanced touch to the DRM cycle and is a potentially useful starting point for review processes.

[**Figure 3***: Complementary DRM Cycle (Sawalha, 2020)*]

Given that there are many different versions and conceptions of the disaster-risk management cycle, conducting a thematic analysis to get a summarised idea of the concept is crucial. There are different types of models. Logical models typically split disaster-management across three distinct phases: before, during and after. Integrated models are more implementation oriented. They consist of independent elements such as hazard identification, preparedness and monitoring which all have their unique boundaries and procedures. This allows such a model to be fluidly applied. Causal models typically focus on underlying causes which lead to disaster and also focus on risk to property and life. Combinatorial models use a mix of logical, integrated, and causal models. Finally, there are miscellaneous models which would not fit in the aforementioned categories of models and usually have a unique approach/focus to disaster management (Nojavan et al., 2018).

Three key themes tend to emerge from a variety of disaster risk management models, namely: hazard assessment, risk management and management action. Hazard assessment involves identifying possible risks/danger and planning for them. Risk management usually includes gathering information about identified risks and further mitigation planning considering resources, organisational responsibilities, and potential impacts. Management actions involve the process-side of the model. It includes but is not limited to prevention, mitigation, response, and recovery processes. Overall, any disaster-risk management model needs to be three dimensional to be truly comprehensive (Nojavan et al., 2018)

Applying the above, it becomes apparent that the DRM model appears to be logical given the clear sequences. However, it is still possible to involve independent elements running across these stages, thus it is possible for the DRM cycle to be an integrated model. Therefore, it is argued that the DRM cycle is a combinatorial model. Considering the three major themes of hazard assessment, risk management and management actions, all of them could be addressed within the scope of the DRM model (UCF, n.d.). The assessment of hazards and risk management are already salient and inherent part of the models. The assessment of hazards plays a key role in the prevention stage as one needs to know what disasters are likely to occur to adequately prepare for them, which are addressed in the subsequent stages of the model. The aspect of risk management is also visible across all stages ranging from assessing risks, contextualising the model to ensuring proper recovery and risk minimisation. The stages of the cycle also correspond to management actions which can always be contextually defined. Given the above information the DRM cycle can be used for the purposes of our literature review/research without further changes (UCF, n.d.). The model's generic nature will allow us to flexibly apply it to various case studies through contextualisation. What will be done before examining the case-studies is preliminarily identifying which emerging technologies are relevant for which stages (Section 2.1. Technology as Lens).

1.4. Stakeholders

Given that disasters affect all individuals on the planet, everyone could be a potential stakeholder in DRM. However, for the purpose of this investigation, defining stakeholders is crucial to ensure an appropriately broad focus without stretching the investigation thin. Based on the timeframe and logistics of this research, 3 stakeholders would be identified and investigated.

The UN recognises the multi-stakeholder nature of DRM and thus the need for both coordination and consistent efforts from all. One stakeholder consistently identified by the UN is the government. The government is a key coordinator which synchronises other stakeholders as well as work in unison with other governments. The government functions at both international, national, and local levels and thus is, in itself, a complex structure. However, in general there seems to be consistent emphasis on the role of the government with respect to complex issues such as DRM and climate change. In addition to the government, the definition of other stakeholders remains vague.

However, the general public appears to receive implicit emphasis. The UN strongly recommends governments to use participatory approaches to develop contextually relevant solutions to climate change and natural disasters. The Rio Declaration signed in 1992, stated that an informed population could contribute significantly to making environmentally and socially optimal decisions which can further inform future policies. Additionally, the average citizen plays a key role in identifying potential problems and raising them to the relevant authorities (Bello et al., 2020). This focus on the bottom-up approach is also reflected in the Sendai Framework for DRM. Meaningful participation from stakeholders is key in monitoring and managing disaster risk and in ensuring the resilience of all communities, institutions, and governments. One possibility would be to encourage the citizens to keep informed and play a role in DRM, to create a culture of disaster resilience. The Sendai framework identified 'civil society' as one possible stakeholder in DRM. This includes NGOs, women, youth, the differently abled, the elderly, indigenous people, and migrants. While these subcategories are themselves diverse groups, they are separated from academia/scientists and business professionals (UNDRR, 2015). The identification of women as stakeholders is a recent development when previous iterations for disaster frameworks assumed the citizenry to be predominantly heterosexual, male of a dominant race. Women, along with other identified groups such as the elderly, children and indigenous people form the majority of the civil society. Their concerns, especially post-disaster, are unique and must be considered and addressed if social resilience is to be achieved (Kimber & Steele, 2021). Furthermore, the civil society is again identified as a key stakeholder in other studies regarding both flood-risk and general disaster risk. Their roles include providing crucial local knowledge as well as spearheading community-based initiatives alongside government investments to engage all members of civil society. The heterogeneity of stakeholders that are considered civil society is also noted in another research (Al-Manji et al., 2020; Raikes et al., 2021; Šakić et al., 2021; Matsuoka & Gonzales, 2021). Therefore, it would be useful to consider 'civil society' as one of the three stakeholders for this investigation.

The government is consistently referred to as a stakeholder in DRM. They are expected to play an important role in coordinating DRM as well as organising and facilitating other stakeholders to contribute to DRM. This is often achieved through the creation and implementation of policies which could take the form of schemes, laws, or institutions (UNDRR, 2015). The role that government policy plays in ensuring human development which in turn strongly links to DRM is noted in research. There is a need to have multi-level and multi-sector governance to enhance resilience. Key issues which were considered included making DRM information mainstream in development planning. Health and access to clean water/sanitation are crucial in guaranteeing resilience in disaster and affect all of civil society. Government policies play a major role in ensuring these basic needs (Raikes et al., 2021). Additionally with regards to research in DRM, an increased emphasis is placed on the role of local, indigenous knowledge generated from the general public (UNDRR, 2015; Bello et al., 2020). This is especially important given that government policies are usually informed and implemented using a top-down approach. Government policies which focus solely on scientific knowledge and centralised management are key factors holding back the implementation of the Sendai framework (Šakić et al., 2021). The government is also identified as a key stakeholder in the enhancement of resilience and DRM by providing public education. Additionally, the use of laws such as building codes are also a key aspect of the government's role and the significance of its investments and actions (Al-Manji et al., 2020). Given the central role that the government plays in DRM, they are a useful stakeholder to investigate.

Businesses and the private sector appear to also get a separate emphasis in the Sendai Framework. They are highlighted for their potential role in engaging and developing new technologies in DRM, developing normative standards, powering investment in resilient infrastructure as well as engaging in socially responsible actions such as providing DRM training (UNDRR, 2015). UNDRR conducted a conference in 2017 to better outline the roles businesses play in the DRM cycle. The report identifies the broad private sector as a third stakeholder in addition to the government and civil society. Their role in the supply chain and the provision of employment is of particular importance. Additionally, a business's ability to invest, the possibility to invest in developing new technologies as well as improving their own resilience and by spill-over effects on civil society and the government, is also considered (UNISDR, 2017). Academic literature also cites the importance of entrepreneurship in disaster recovery. Investigations by Chamlee-Wright and Storr (2008) demonstrate that economic entrepreneurship plays a fundamental role in ensuring the provision of goods and services post-disaster. They further argue that social entrepreneurship makes direct changes in society through their work. These social entrepreneurs include a wide range of actors such as NGOs, religious institutions, civic organisations, and community members. They distinguish social entrepreneurship and economic entrepreneurship based on their intention to make profits. They further argue that both entrepreneurs face significant regulatory barriers, an issue noted in the UNISDR conference. Therefore, a need to remove restrictive regulations is a sentiment echoed in both cases (Chamlee-Wright, 2008; UNISDR, 2017).

While large corporations, established companies and research institutes with a profit orientation all fall into this third "Private" stakeholder category, they will be sidelined to make room for the identification of start-ups founded by Entrepreneurs. This will include both start-ups that are funded by private people and start-ups funded by governments of transnational governmental bodies such as the EU. Since this report is dealing with technologies, an inherent limitation will be the recent founding of the respective start-up. Only companies founded after 2015 will be considered. Concerning the Maturity of the company the following five differentiations will be made: A - Prototype testing in the lab, B - Prototype testing in the real world, C - Initial market commercialization, D - Small scale commercialization and E - Medium and large scale commercialization (adopted from Impulse, 2021). This means that companies in the conceptual stage, without a prototype, will be excluded. At the opposite side of the maturity spectrum, companies beyond large scale commercialization will not be included. While this limitation to start-ups can be considered to restrict the report´s findings, it can also be seen as enriching its merits. This is because an in-depth analysis of most impactful companies, at least in the conventional business sense of profitability, revenue and sales will lead to the selection of the biggest players. Indeed, the Incident and Emergency market is saturated with large, global players with small- and medium companies and start-ups playing a marginal role (Emergen, 2022). Hence, from the perspective of the researchers, restricting the review to start-ups will open up the possibility to consider the role of young and social Entrepreneurs in the context of Disaster Management.

S/N	Stakeholder	Entities	Powers/Abilities	Interests
1	Public	Governments, UN	Substantial Financial Resources, Legal/Regulations, Technical Capacity for Large-scale Interventions	Flood Prevention, First Response, Large-scale Infrastructure, Public Service Continuity, Cost-Effectiveness
2	Social	Civil Society Organisations, Grassroots Movements, Neighbourhood Associations	Communication with communities, Local Knowledge, Contextualising Technical Information	Damage Mitigation, Supplementary Response, Local Actor Empowerment, Rapid Recovery Processes, Stakeholder Integration
3	Private	Established Private Firms (excluded from review), Start-ups, Social Enterprises, Thinktanks	Technical Capacities for Interventions, Local and Global Knowledge Networks, Innovation, Research & Development	Profits, Social/Environmental Impact, Sustainability of Business Model, Damage Minimisation

2. Technology as a Lens

Technology is a major theme of the Sendai Framework. It is cited as one of the underlying drivers of vulnerabilities and also seen as a solution to reducing disaster risk. Technology is acknowledged as a key aspect to consider in all stages of the DRM cycle ranging from prevention such as engineered solutions through new modelling over preparedness such as multi–hazard early warning systems to post-disaster recovery and reconstruction. Technology transfer from developed countries to the emerging world is also emphasised as a possible solution to disaster risks. With increased urbanisation and concentration of population, infrastructure and economic activities in cities, technology is increasingly recognised as a solution that can manage the increased risks faced by humanity (UNDRR, 2015).

Technology is also discussed with respect to various stakeholders. This includes policies that regulate the application of technologies and improving the science-policy interface where communities involved in scientific and technological developments inform policy decisions. Similarly, the framework accepts that solution-oriented funding of technological research and development is also required, especially from the private sector. The Grand Bargain framework which aimed to aggregate reliable, flexible, and accountable funding for humanitarian aid also made use of technological innovations and funding to improve operations (Inter-agency Standing Committee [IASC], 2019). While technology is not explicitly addressed in the Grand Bargain 2.0 framework, the need for funding local actors and national responders is included as a central outcome. However, all its four major pillars could be addressed partially through technological means (IASC, 2021). In addition, the theme of bottom-up participative risk management underscores the need for technological support such as geographical information systems (GIS) in generating risk data (UNDRR, 2015; IASC, 2021). Recent papers point out the importance of GIS and other emerging technologies in the area of Disaster Management (Vermiglio et al., 2021)

While technology itself is not an end-goal or outcome of disaster management, it is a highly versatile tool. This means that a technology which may appear less relevant with respect to DRM may be very useful during a disaster. To exemplify, car manufacturers who can track their vehicles can make use of this user base to analyse which roads are still functioning after a flood or earthquake (Lutken, 2021). Technology also plays different roles in different stages of the DRM cycle. Information technology has been used to monitor situations prior to disaster to improve preparedness. Information technology has also been used to coordinate and calibrate disaster relief based on geographical information. Technology also involves and affects multiple stakeholders including the general public, the government and the private sector (Sakurai & Murayama, 2019; Lutken, 2021). The definition of technology is not limited to software like GIS and information technologies but also engineered solutions. To elucidate, Hong Kong stabilised slopes along various channels with geo-fabric reinforcement to reduce the risk of landslides and enhance flood drainage (Chan et al., 2018).

In summary, technology is increasingly seen as a relevant tool in DRM. While it is often not an end-solution, its tactful and creative application by various stakeholders in DRM could greatly contribute towards reducing underlying hazards and vulnerabilities. In an increasingly techno-centric world, understanding DRM through a technological lens would be useful for stakeholders as well as future scholarly publications to better assess the role of technology in DRM. Hence, the researchers intend to use technology as a lens in this investigation.

However, for the purpose of this report a rather broad definition of technology is used. While the technologies outlined are predominantly engineered solutions (commonly known as grey or structural measures) and information technology (non-structural measures), many nature-based and socio-technological solutions are considered.

The end user or beneficiary of any given solution to flood-risk is a social individual. Thus, these infrastructures have socio-technical impacts that must be accounted for. Thus, by integrating a social angle in a technology review, the utility of the technology and the role of resilience is better understood. Thus some case studies may be categorised as a socio-technological solutions (Rahimi-Golkhandan et al., 2022).

In this era of climate change a new paradigm for multi-functional infrastructure has evolved. Thus, nature-based solutions have become increasingly seen as a unique set of solutions to climate adaptation challenges. A nature-based solution can range from restoring natural processes to mimicking in built areas. These solutions are increasingly seen in the European Union and have been rapidly adapted in dense Asian cities as well, establishing an entire new slew of solutions and approaches to flood management. The benefits nature-based solutions have to offer beyond flood-management and their potential sustainability and versatility have made them a new contender to grey-structural measures (Hartmann et al., 2019). Thus, including these in a review would be important to present up to date information and trends.

To that end, a review of some established and emerging technologies in the Prevention and Mitigation phase will be conducted. These technologies are mainly structura in nature, with a few exceptions. This review will limit itself to relevant publications from 2020 onwards.

After concluding key technologies in the first two stages, the following three stages of the DRM cycle will be considered: Preparedness, Response and Recovery. These technologies are mainly non-structural. The review will focus on emerging technologies rather than established ones since the focus of this report is a very recent and future outlook. Like the first stage review, relevant publications from 2020 onwards will be considered.

Finally, a market analysis of the Incident and Emergency Market from Emergen Research (2022) will be conducted. The main purpose of this market analysis is to give enough background knowledge and overarching context for the best-practice socio-technological solutions found in the Entrepreneurship/Start-ups stakeholder section.

2.1. Emerging technologies structural: Grey and green[1]

While there was a stark focus on single-purpose-grey infrastructure for a long period, the landscape of preventative and mitigative technological and techno-engineered solutions is changing. One of the most promising and most cited new solutions are Nature-based solutions (NBS). One broad and renowned definition of NBs is: “actions to protect, conserve, restore, sustainably use, and manage natural or modified … ecosystems, which address social, economic and environmental challenges effectively and adaptively ” (NBs Initiative & University of Oxford, 2022).

Reviews of NBs point to their increasing popularity globally (Kumar et al., 2021). Researchers increasingly find evidence that strongly suggests that NBs have myriad benefits. First, they can effectively regulate bio-geophysical processes driving hazards (Nelson et al., 2020). Secondly, they have many additional benefits that single-purpose, grey solutions cannot deliver. This includes cleaning water naturally, creating fresh air, recreation also in the urban sector, access to green spaces and provision of natural capital (Kumar et al. 2020, Anderson & Renaud, 2021).

Showcasing the benefits of these NBs and making results available to citizens can increase the visibility and credibility of said solutions to accelerate wider adoption. This should and can encourage the involvement of citizens and create trust of various stakeholders in these solutions (Kabisch et al., 2017; Kumar et al., 2020).

However, Kumar et al. (2021) explain that general uptake of NBS is still slow due to the lack of internationally recognised and comparable standard methods for assessing their multi-functional performance, hindering the establishment of a solid evidence base showcasing the benefits of NBS over conventional grey approaches for hydrometeorological risks (HMRs) management (e.g., Nelson et al., 2020).” Nelson et al. (2020) furthermore exemplify which exact challenges still exist to the adoption of NBs and realising their immense potential.

Against this background, it appears indispensable to review technologies in the NBs sector concerning disaster management. This will include nature-based engineering solutions implemented at specific locations but also software modelling of NBs, which has the potential to increase adoption and decrease failure rate (Kumar et al., 2021).

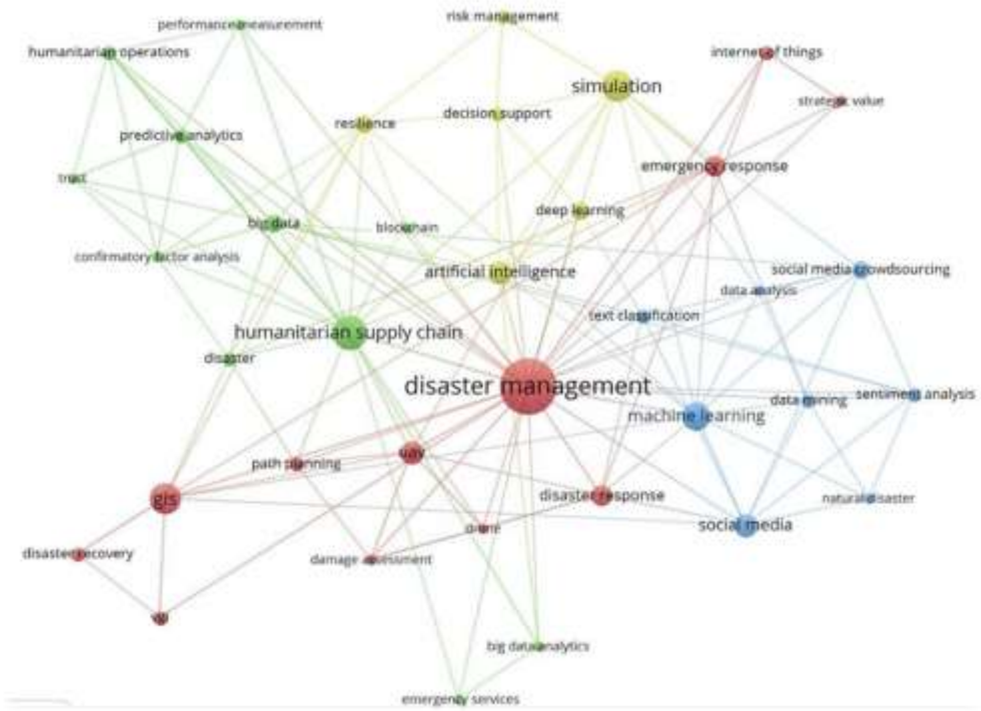
Despite the rising popularity and support for NBS, grey infrastructure remains important to many flood-prone cities today as their primary mode of investment in flood-management. This is particularly relevant to the global South[2], where populations can be concentrated along flood plains and coastal regions which are more vulnerable to climate change. The operation of flood-control structures such as dams, canals and embankments are crucial to ensure the safety of populations as they are able to eliminate the underlying risk of flooding to some extent (Ogie et al., 2019).

[1] Interested readers may consult the following link for Kumar et al.´s review (2021): https://www.sciencedirect.com/science/article/pii/S0048969721021288
And the following link for Nelson et al´s publication on challenges to realising NBs´ full potential: https://www.sciencedirect.com/science/article/pii/S1877343520300750

[2] Interested readers may consult the review by Ogie et al. (2019): https://www.tandfonline.com/doi/abs/10.1080/09640568.2018.1547693?journalCode=cjep20

Given their fundamentally high risk levels associated with climate change, countries in the global South may need to continue to invest in grey structural measures which can then be complemented with nature-based or non-structural measures. In addition to that, the complementation process needs to be inclusive of the local socio-politico-economic context to ensure that the benefits of a grey structural measure fully reach vulnerable populations thereby improving their resilience (Ernst et al., 2020; International Centre for Integrated Mountain Development, 2012).

2.2. Emerging technologies non-structural: Disaster Management



[***Figure 4***: *Network visualisation of identified ETs (Vermiglio et al., 2021)*]

A recent review whose original purpose was to analyse how emergint technologies (ETs) impact improving performance in DM, provides a very helpful guide in identifying and contextualising the various new technologies in DM[3]. The review published by Vermiglio et al. (2021) employed a systematic review of scientific literature to find 69 publications which were clustered in the bibliometric visualisation of Figure 4.

Vermiglio et al. (2021) identified simulations in the yellow cluster to play a major role in the Preparedness stage. The yellow cluster includes ETs that make experimenting with a disaster in the virtual world more effective and efficient. Simulations play a key part in increasing resilience to disasters since they are one of the only ways to explore how DM plays out and where levers to increase performance in managing disasters like floods lie (Noto and Cosenz, 2021). There are several simulations in DM studies[4], one of which is Agent Based Modelling which according to Vermiglio et al. (2021) "has shown effectiveness in considering the behaviour of the multiple agents involved in the DM cycle[5]" (Mishra et al., 2019). A highly interesting case-study is one by Fan et al. (2021) which employed the vision of a Disaster City Digital Twin paradigm that includes Artificial Intelligence (AI),

[3] This synthesis of Vermiglio et al.´s (2021) publication and the report´s conceptual framework
served the purpose of giving the reader a broad overview of the emerging technologies
in DM. It is not exhaustive and had to exclude important parts of Vermiglio et al.´s (2021) publication.
However, the researchers of this report believe that this synthesis is helpful in guiding the
reader into an extremely broad review of best-practice technologies.

[4] Please consult Vermiglio´s et al.´s (2021) publication which discusses the different simulations.

[5] Please note that the DM cycle identified in Vermiglio´s et al.´s (2021) publication is not the same as the one of this report. However, the key components of the Preparedness, Response and Recover stage as identified in this report are reflected, hence the the term DM cycle as Vermiglio et al. (2021) use it can be adopted and understood in a very similar fashion as the one defined in this report.

informatics and information and communication technology (ICT) to create transparency and visibility in the complex dynamics of DM[6].

In the red cluster, Vermiglio et al. (2021) identified ETs to support stakeholders in the Response phase. The identified ETs in this cluster are geospatial data (GIS), volunteered geographic information (VGI), Internet of Things (IoT) and robotics automation (RA). Vermiglio et al. (2021) noted an interesting finding when synthesising scholars that wrote about GIS and VGI in DM: "Some scholars cleary described the complementary role of GIS and VGI in the provision of information, which can be helpful in coordinating response tasks amongst volunteer groups and official disaster agencies (Hung et al., 2016; Contreras et al., 2016; Schumann, 2018; Akter & Foss Wamba, 2019; Sharma et al., 2020)[7]." However, Vermiglio et al. (2021) also recognize that some scholars still observed challenges concerning information technologies in DM, such as lack or resources of poor data quality (Haworth, 2016).

In the blue cluster, Vermiglio et al (2021) identified the ETs of data mining, machine learning and social media which can improve the performance and accountability of DM actions throughout the stages of Preparedness, for example in early warning systems, Response, e.g. more data can be processed to make solid decisions and Recovery, for example image recognition for various recovery actions.

The final green cluster focuses on the importance of big data and predictive analytics for disaster relief operations. Vermiglio et al. (2021) identified that many scholars point to the benefits of big data in improving transparency, cooperation and coordination and sustainable recovery from disasters (Papadopoulos et al., 2017; Dubey et al., 2018; Dubey et al., 2019; Jeble et al., 2019; Ragini et al., 2018)[8].

Since the nature of Vermiglio et al.´s (2021) review and visualisation was very broad in nature, the articles discussed have different methodologies and definitions of DM. This inconsistency in using the term DM, as well as the respective stages of the DM cycle, especially Preparedness, Response and Recovery somewhat limits the applicability of scientific publications to the real world. It can raise confusion among stakeholders.

However, Vermiglio et al.´s (2021) review and visualisation proved to be a great help in mapping emerging technologies. It shall lay the foundation for the reader to orient the best-practice technologies that will be identified in this report.

2.3. Market analysis of Incident and Emergency Management technologies Private sector

Before finishing the technology section of the conceptual framework, a market analysis of the incident and emergency market, to which the disaster management sector belongs, will be conducted. Hence, this is a market analysis of the industry sector of technologies in the preparedness, response and recovery stage. This analysis is indispensable given that one of the three stakeholders in this report is the private sector, more specifically the entrepreneurship and start-up sector which relies heavily on upcoming trends in the industry. The market analysis shall help business readers of this report to better identify where the best-practices are positioned in the broader competitive market and how they can serve potential customers (Kuligowski, 2022).

To that end, the market analysis of Emergen Research, a research and consulting firm focused on the most recent industries and new developments, will be synthesised with the previous section 2.2. which focused on academic literature of DM (Emergen Research, 2022a). While there are myriad established and professional market analysis on the Web, the researchers chose this one, since it was freely accessible while still providing, to the best judgement of the researchers, a holistic and trustworthy outlook of the market. Furthermore, the market analysis was published only last month, so in June 2022, making it one of the most recent available to the researchers (Emergen Research, 2022b).

However, Emergen´s market analyses is very broad in nature: it considers the complete incident and emergency management market from 2019-2030. This means it is not restricted to natural hazards but includes any other emergency and incident technology; like Software as a Service (SaaS) in preventing cyber attacks in the banking sector. This means that the researchers will exclude certain parts of the freely accessible market

[6] Interested readers may consult the paper by Fan et al. (2021) under the following link: https://www.sciencedirect.com/science/article/pii/S0268401219302956

[7] It was impossible for the researchers of this report to review in-depth all of these scholar's publications. However, they will be cited in this report for reference & future research

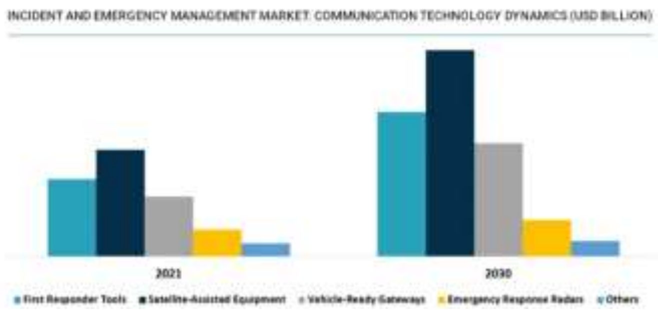
[8] Please refer to the previous footnote.

analysis to the relevant ones in light of this report. Since the general statistics do not differentiate on hazard type, they are not meaningful in determining the exact share of flood disasters but rather help position flood technologies in a broader context.

The most essential of these general statistics is the registered Compound Annual Growth Rate (CAGR) of 7.0% that the global incident and emergency market size will grwo during hte forecast period of 2019-2030. The current market size was $124.88bio in 2021. Emergen Research (2022) identifies several drivers of this growth which are not unlike the one´s driving natural hazards in general. More specifically, concerning natural hazards, the analysis refers to a “Rise in frequency of natural disasters in recent years, such as heavy snowstorms in Spain, floods in Western Europe, cyclone Yaas in India, and others, are leading to economic losses and are driving revenue growth on the market”. As driving buyers and investors in technologies Emergen Research (2022) identifies the following: “Incident and emergency management market revenue growth is primarily driven by rise in number of investments in disaster management solutions by governments in developed and developing countries.”

Concerning the segmentation of the general industry, Emergen Research (2022) differentiates among others, by system type and communication technology. By system type it first points to Web-based emergency management systems which is predicted to grow rapidly during the forecast period. Cloud-based emergency management systems are highlighted which can provide help rapidly and are more time and resource efficient and guarantee data recovery. These systems are essential for the cyber are of emergencies but play an increasing role in disaster management as well (Crichton, 2021; K.C. et al., 2019). The other segments differentiated by system type are mass notification systems, disaster recovery and business continuity and geospatial. All are expected to increase over the next years. Finally, the systems of Fire and Hazardous Materials account for a significant revenue share last year due to an increase number in terror attacks, civil unrest and internaitonal attacks and harazdous material incidents but also natural casues like wild fires.

As a second important segmentation of the general industry, Emergen Research (2022) differentiates based on communication technology: First responder tools, vehicle-ready gateways and emergency response radars. An disproportionate focus of the market analysis concerns satellite technology i.e. Satellite-Assisted Equipment. Emergen Research (2022) provides a visualisation of the differentiated communication technologies that exemplifies this disproportion well:



[***Figure 5***: *Communication Technology Dynamics: market share in $bio in 2021 and 2030 (Emergen Research, 2022)*]

Emergen Research (2022) predicts the revenue growth of satellite-assisted equipment to increase at a stable rate during the forecast period. Furthermore, as seen in the graph, first responder tools are also predicted to increase at a stable rate until 2030.

Besides satellite-technology, a second segment stands out in the market analysis: Simulation. This includes Traffic simulation systems, Incident & Evacuation Simulation and Hazard Propagation Simulation Tools. While not restricted to natural hazards, the trend in an increase of simulation technologies is coherent with the previous review of Vermiglio et al. (2021) who point to scholars writing and advocating established and new simulation technologies (Fan et al. 2021; Noto and Cosenz, 2021). Emergen Research (2022) conclude the following about simulation technologies:

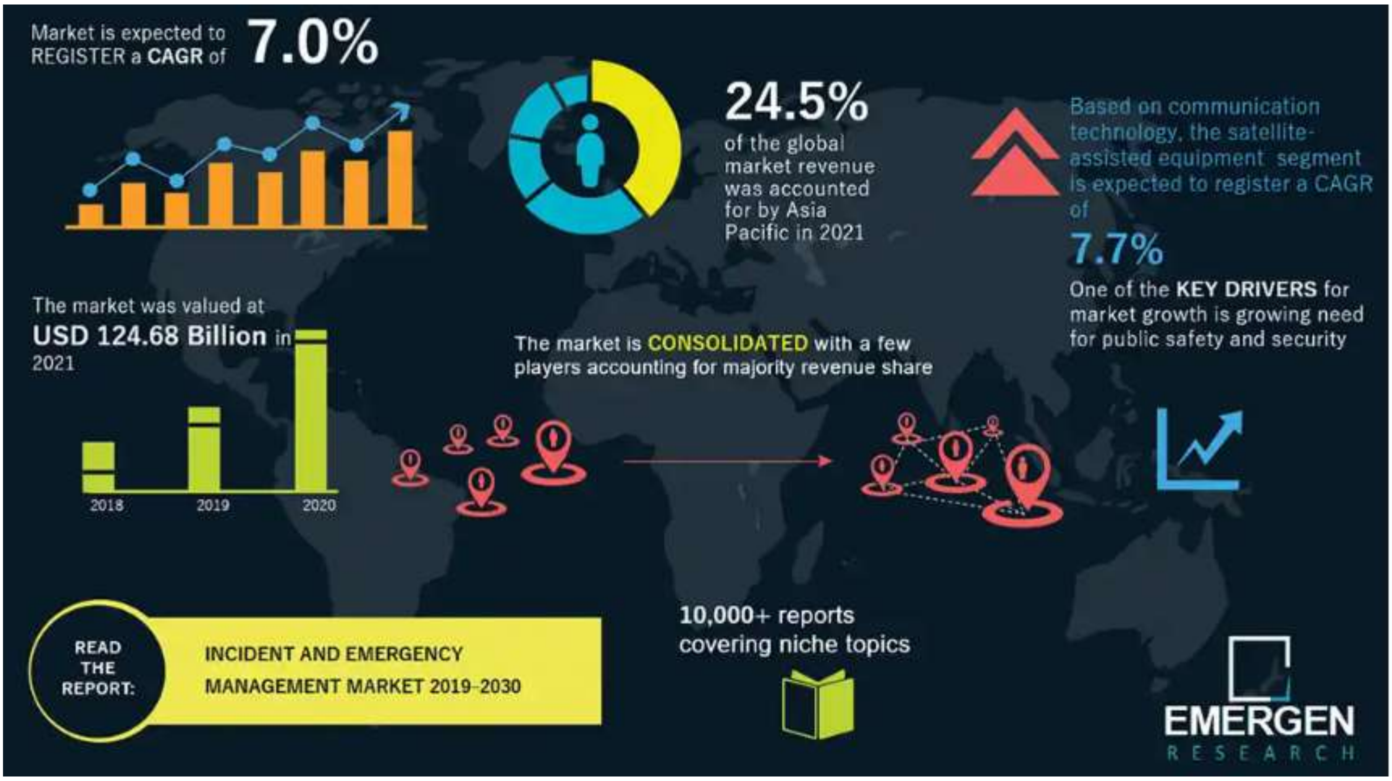
- “The incident and evacuation simulation tools segment accounted for largest revenue share owing to increasing demand in commercial and residential buildings.”
- “Different evacuation simulation software are used in commercial evacuation simulation systems, such as Pathfinder and STEPS, are used in commercial evacuation simulation systems, whereas, Repast, NetLogo, and Swarm are used in open-source evacuation simulation systems.”

A final segment of the Incident and Emergency market is Service which includes “consulting, emergency operations centre design and integration, public information services, training and education, support and maintenance, and others (Emergen Research, 2022)”. The segment is expected to register a steep growth until 2030.

While Emergen Research´s market analysis (2022) predicts a stark growth, it also mentions certain barriers in the market. For example, many technologies and R&D in emergency management requires high maintenance costs. Additionally, false alarms, inadequate education and training are restricting revenue growth, and for that matter, increase in resilience towards disasters.

Finally, “a lack of allocation of budget for incident response solutions and services, especially in emerging countries, is also hindering growth of the market. (Emergen Research, 2022)” This confirms previous parts of the conceptual framework explained the vulnerability and disadvantage of the vulnerable.

To give a more visual representation of this conclusion, the following infographic created by Emergen Research (2021) can provide a useful overview:



[***Figure 6***: *Infographic of Incident and Emergency Market, forecasting period 2019-2030 (Emergen Research, 2022)*]

3. Best Practice Research

Despite its myriad applications, technology is not a panacea for disaster management. Understanding when and how to use technology is of significant importance if the goals of the Sendai framework are to be achieved (Lutken, 2021). Academic interest and output with regards to disaster management has increased exponentially in the last 3 decades. Vulnerability, resilience, and logistics have emerged as common themes visible amongst publications from the previous decade. As evident from Section 2, Technology as a Lense, technology is among the aspects explored in some of the most cited studies of the previous decade. Technology has emerged as a key factor being studied in the most recent emergency management literature. However, with the exception of Vermiglio et al.´s study (2021), most publications have focused predominantly on the potential of information technology and big data (Oh & Lee, 2020). While information technologies are essential and will be considered in this review, they are one of many essential technologies to address the growing challenge of natural disaster. One question that can be raised from this discussion is how to determine and seek examples of technologies well applied in the DRM context? Furthermore, how could technology, the DRM cycle, and stakeholders be related? One possible answer to these questions are reviews, which can summarise, synthesise, and standardise the knowledge in a particular domain or field. Given the volume of literature and information generated annually in relation to DRM and technology, a review could be a useful tool to guide future research as well as non-academics (Paul & Criado, 2019; Oh & Lee, 2020). This raises another question: what kind of review should be conducted? What should be its aims and possibly its output?

A best-practice approach could be a useful tool. A best practice is one that is functional, process-oriented, and innovative. It focuses on the most ideal way in which a problem could be approached and then addressed. A best-practice approach is typically used in policy studies to determine the efficacy of a variety of solutions to a given problem or to judge the optimality of policy processes and their impact on outcomes. However, their final aim after reviewing all possible practices is to highlight what is required of an optimal practice and identifying said optimal practice. Therefore, the researchers believe that conducting a best-practices research approach would be useful to highlight optimal uses and approaches to technology in disaster management by the different stakeholders (Veselý, 2011).

Yet, another question emerges from this discussion: If best-practices are to be reviewed, what kind of studies should the review be based on? Quantitative, qualitative or mixed-methods literature? Looking back at the various kinds of best-practice research methodologies a binary is visible. If the emphasis is to find examples, then a quantitative focus is suggested. However, if the focus of the review is to understand the possibility of applying a given practice, a qualitative route is preferred. However, exemplar identification is not the sole purpose of our review, as the identified exemplars could be applicable to other scenarios. Given that a case study also has a unique context, qualitative information may help capture certain facets of a technology or stakeholder which would allow us to extrapolate these best practices if necessary (Veselý, 2011). Therefore, to ensure that this review is comprehensive, the researchers employ a mixed-methods review and include both qualitative and quantitative studies in a best-practices review.

Finally, the most important question to ask is if a best-practice review is actually required? One of the most recent studies and data available specifically considers the role of knowledge management in flood-risks and a bibliometric analysis of ETs for performance management in DM (Oktari et al., 2020; Vermiglio et al., 2021). While such reviews are highly important, they do not provide an in-depth understanding of the potential applications of technology in disaster-management. Thus it does not satisfy the aim of this research.

Research by Trogrlić et al. (2017) has researched the importance of science and technology networks in DRM. However, among the key findings of the research was that a need for highlighting and publicising good technological practices was required by these networks to better operate, innovate and transfer knowledge across borders. Hence, the importance of technology in DRM cannot be understated.

Even the most recent research continues to call for reviewing and highlighting technological best-practices. Oo et al. (2020) emphasise the need for technological best-practices to be reviewed and identified for the purpose of integrating the diverse stakeholders mentioned in the Sendai Framework as well as to emulate these practices on a global scale to impact the most number of vulnerable people. Thus, a review of best-practices in technology to adapt to disaster risks are a key to the solution for DRM.

4. Flood Risks

The ground-breaking review by Oo et al. (2020) was specifically focussed on floods which disproportionately affect those in the global South and whose risks have been increasing with changes in climate patterns over the preceding decades.

Natural disasters take various forms including but not limited to floods, storms, earthquakes, droughts, landslides, and extreme temperatures. Statistics from the Centre for Research on the Epidemiology of Disasters (CRED) demonstrates that flooding has by far been the most severe disaster in 2018, as well as the 17 previous years. Flooding accounts for only 5,424 of 77,144 disasters between 2000 and 2017 annually, making it only the fourth most common type of disaster. However, floods accounted for 86,696,923 of the 193,312,310 people affected by disasters annually in the same period (CRED, 2019a). Of the 61,772,617 affected individuals in 2018, floods contributed to 35,385,178 victims. In terms of death toll, four of the top ten disasters in 2018 were floods (CRED, 2019b). In addition to affecting the largest number of people, flooding also appears to be a costly disaster causing 22% of all damages from natural disasters between 2000 and 2019 amounting to US$ 651 billion. This number would be even higher as the cost of disasters tend to be under-accounted for in Asia and Africa where flood events are most prevalent. Flooding is also noted as one of the most preventable natural disasters given the affordability of mechanisms to manage flooding (UNDRR & CRED, 2020). Currently, over 1.47 billion individuals are at risk of flooding. Nearly half of them are located in densely populated Eastern and Southern Asia. Roughly half of these at-risk individuals come from lower income families who lack resources to react to and recover from flooding (Rentschler & Salhab, 2020). Thus, it can be observed that applying the principles of DRM to managing flood risk would benefit the largest number of people. This is especially relevant with the continued urbanisation and concentration of economic activities in low-lying regions which are easiest to develop and the rise in sea levels (UNDRR, 2015; IPCC, 2022a). Henceforth, this report shall continue this investigation with respect to DRM in flood risks.

5. Review Question

Following from the previous discussions, this report arrives at a review question: *What is the role of technology in disaster risk management for all stakeholders in* *society?* Taking into account the conceptual framework, this question can be further specified.

Firstly, when considering the role of technology with respect to DRM, this report essentially intends to understand its efficacy. Since a best practice approach will be employed, a gauge is required - the concept of resilience will be used as the measure to distinguish which practices are better than others. This gauge will hence inform the Assessment framework

Secondly, stakeholders are specified to be policymakers (the government), society (general public) and entrepreneurs (private sector).

Thirdly, disasters are diverse in nature and so are the risks contributing to the hazards and vulnerabilities which are the underlying cause of disaster. Given that the literature in this field is vast and diverse, it would be incredibly challenging both conceptually and logistically to conduct such a review in a short period of time. Hence, based on statistics, the researchers conclude that flooding affects the largest number of people and is also linked with climate change which is also increasingly discussed in academic and non-academic circles. Thus, the researchers believe that investigating flood risk would be useful.

Fourthly, disaster management and the theories defining them have given rise to various models. However, the cyclical conception of DRM is widely used in academia and also referred to in the Sendai framework. Hence, this report also adopts this cyclical model of DRM.

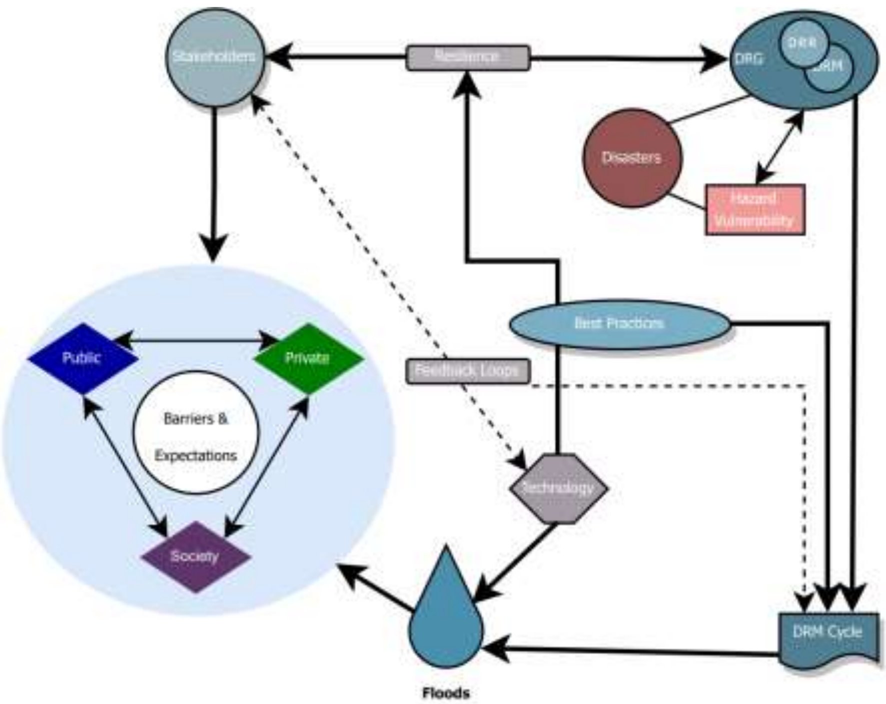
Taking these arguments into account, the researchers arrive at the final review question: How can flood-risks be managed better and what are the future outlooks?

From the above review question, emerges our first research question: Which technologies best increase resilience to flood disaster among the public, social, and private sectors in the five stages of the disaster risk management cycle? This report aims to identify best-practice technologies or use of technologies in enhancing disaster resilience.

However, while identifying best-practices in flood-risk management is indeed valuable output, there is also a need to understand how this risk landscape changes and how these stakeholders interact with each other (Oo et al., 2020). These technologies have social impacts and thus are known as ‘socio-technological solutions.’ Thus, the powers and interests of each stakeholder come into play and are important to account for when considering the future applications of the suggested best-practices from the first research question. Henceforth, a second research question is asked to follow-up on this fundamental gap in research: What barriers and expectations among stakeholders concerning best-practice socio-technological solutions exist and how can exposing them accelerate societal adoption and sustainable transformation?

Given the above research questions we come up with a simplified conceptual framework which summarises the concepts and context within which this review will be conducted.

[***Figure 7**: Visualisation of the Conceptual framework created by the researchers themselves*]



Referring to the above diagram, various key concepts discussed in this section and how they relate to each other are summarised using arrows. Firstly, disasters of any kind are caused by the interaction of hazards and vulnerabilities. DRR is the main strategy used to combat these underlying hazards and vulnerabilities. DRG refers to the overall system and context in which DRR is conducted and DRM refers to the specific technologies and practices. These practices can be classified into one of the five stages of the DRM cycle.

Technology plays a key role in alleviating the impact of floods on the three stakeholder groups (public, private and social sectors). Excellent deployment of such technology is known as a best-practice which can be adapted globally to combat flood-risks associated with a particular stage of the DRM cycle by a stakeholder group. Such a socio-technological best-practice greatly improves the resilience of the stakeholders to the increased flood-risk driven by climate change.

The implementation of these solutions and adaptation to climate change may have spillover effects across the stages of the DRM cycle or between the diverse stakeholders. These are conceptualised as feedback loops which can be identified over the course of the review.

However, from an implementation point of view, stakeholders have different powers, abilities and interests. This gives each group a unique set of abilities to tackle flood-risks and certain advantages and disadvantages relative to the other. Thus, to better allow for the emulation of these socio-technological best-practices, the barriers faced by stakeholders in implementing best-practices and the expectations that stakeholders have of each other must be considered.

6. Methodology

Using knowledge gathered in time-intensive, rigorously conducted studies is highly complex. Establishing the usefulness of a multi-variety of studies for policy making, for people trying to make a difference in the world and in the end, for society as a whole has proven challenging for many scholars trying to synthesise complex phenomena (Gough, 2007). So also, for this research project aimed at investigating, reviewing and synthesising best-practices for major stakeholders trying to increase resilience against disasters.

The research area itself being on the one hand highly complex and the method limited to qualitative methods of analysis and synthesis, calls for a detailed outline of the planned methodological process. The intended research inquiry is to identify best-practices in the sector of technology in the above established context for several major stakeholders. This review question is complex and hence needs to differentiate in its approach and methods for investigation from a simple research question. While it is evident that some sort of meta review and synthesis is needed, studies and guidelines on these methods of reviewing literature in the social sciences are increasing but still limited. Systematic Reviews as well as Meta-Analysis and Meta-Ethnography (also called Meta-Synthesis), often considered as the qualitative counterpart of the former, have been developed extensively for health/medical interventions (Template University University Libraries, 2022; Department of Health and Human Services, 2017; Sandelowski et al., 2012; Harden A., 2010; Gough, 2007). While systematic reviews can be found for the social sciences in many scientific journals and databases, meta-analysis and meta-ethnographies are still scarce. For that reason, this research proposal methodology used both research guidelines from the health sector and the social science sector where applicable to develop a sound methodological process.

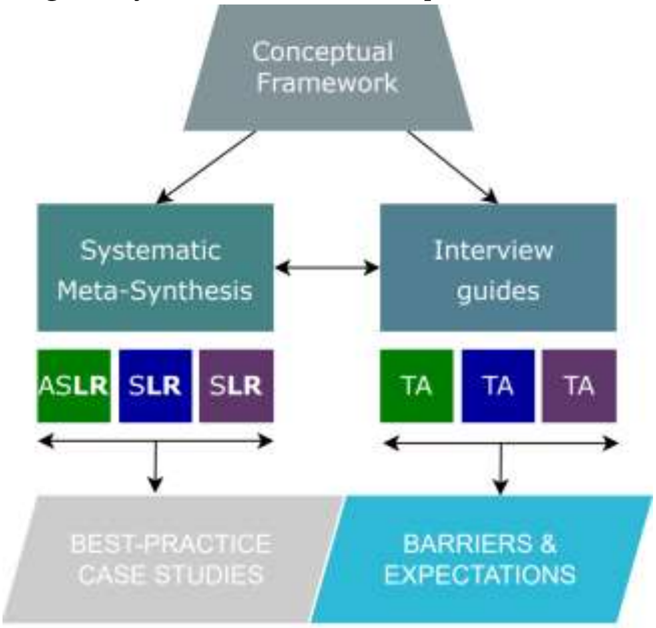
The above background information on reviews, Meta-Analysis and Meta-Ethnography allows the researchers to take up the issue of complexity within the review question. Conducting a search in the methodological literature has shown that when a certain complexity is given, one speaks of a complex intervention (Template University University Libraries, 2022; Department of Health and Human Services, 2017). While this term is the most commonly used in medical research, it can be applied to complex phenomena in the social sciences as well. So also, in this research project. The characteristics of a complex intervention apply clearly to this research project. First, the identification of best-practice technologies for major stakeholders has multiple components. Secondly, the different interactions between stakeholders (government, public, private sector) and technology within the stages of the DRM cycle represent multiple and complicated pathways. Thirdly, the best-practices the researchers aim to identify will target multiple participants, stakeholders, representing population complexity. Finally, implementation complexity, a multifaceted adoption and contextual complexity and working in a multidimensional environment, is also a given (Template University University Libraries, 2022; Department of Health and Human Services, 2017).

Undertaking a review and synthesis of a complex intervention or in this case, a complex best-practice research often requires a partial but substantial adaptation of conventional review and synthesis methods (Template University University Libraries, 2022; Department of Health and Human Services, 2017; Gough, 2007).

This research project started with research and discussion about established theories including a review of recent Emerging Technologies (Sections 1-5 of the Conceptual Framework). This conceptual framework informs the meta-synthesis and according systematic literature reviews for all three stakeholder; an asymmetric (adapted) Systematic Literature Search for Entrepreneurship/start-ups (ASLR), a systematic Literature Search for the Policy sector (SLR) and a systematic Literature Search for the Social sector (SLR).

While conducting the systematic reviews it became evident that explaining the status quo of existing technologies is insufficient in creating valuable research outputs. This stems from the increasing belief that developers behind the socio-technological solutions face myriad barriers to optimal implementation. Further research also showed that some stakeholders can potentially hold resources the other needs. Hence, it became essential to interact with stakeholders and conduct primary research about any challenges, barriers and expectations they have. This led the researchers to extend their methods to conduct interviews. The original conceptual framework was extended to include stakeholder´s barriers & expectations. The resulting framework laid the basis for the interview guides. After conducting the interviews, they were analysed with three Thematic analysis (TA) per stakeholder.

Hence, our output is two-fold: On one side we conducted a systematic review to identify the best-practices. On the other side we conducted and analysed interviews with key stakeholders that resulted in an insightful synthesis of barriers & expectations.



[***Figure 8***: *Visualised Overview of methodological process and output created by the researchers of this report*]

6.2. Systematic Literature Reviews

6.2.1. General Approach

Prior to conducting a literature search, a general search was conducted to understand the nature of literature available and how they can be found. The below methodology was initially developed to use for the public sector literature search and was to be adopted for the social sector and private sector literature searches. However, over the course of the literature search, changes were made to the methodology. An overview of the original method is provided below:

Firstly, after a generic Google search, popular databases were consulted. The simplest keywords ‘policy’, ‘flood’ and ‘technology’ were used to find relevant publications and results were filtered down to the period from 2015 until present day to ensure currency to literature. The databases used were JSTOR, The OECD iLibrary, Web of Science and Emerald Insight.

JSTOR contains a substantial number of policy reviews ranging from more theoretical and conceptual publications to case study specific policy reviews. Many articles with a technological focus tended to be prescriptive in nature rather than focusing on a specific case study and its successed. Many articles provided a general view of policy around technologies and were completely irrelevant to the search topic.

The OECD library had limitations on search term use, so ‘flood’ was used as the primary term. Limited literature was found with specific focus on agricultural policies. Some articles referred to previously successfully implemented policies including constructed infrastructure. These reports could be useful as a starting point. However, the OECD has a strong focus on a limited set of countries, many of which fall outside of Asia and Africa where the most vulnerable populations tend to be.

The interdisciplinary focus of Web of Science ensured that more relevant articles turned up than in the previous database. Many articles had a generic review of technologies which could act as starting points to conduct more specific searches to result in a case study. While the Web of Science has many options to narrow results based on topics, publication type and journal of publication, realising this was challenging and did not guarantee completely relevant results.

Emerald Insight led to some relevant results with many papers focusing on the potential applications of a given technology or generic/holistic reviews of flood policies. In general, the managerial focus of the database resulted in many articles referring to or comparing various frameworks for emergency management, thus proving to be potentially useful literature to develop evaluative criteria at a later stage of this review process.

Overall, the approach yielded many irrelevant results despite refining. This indicates that the keywords used are useful but overly broad and thus additional keywords need to be developed. Additionally, many questions were raised over this stage. In addition to using formal databases, how can grey literature be used as a supplement to gain more relevant data to support our review? Should the kind of technology (engineered, GIS, nature-based) or the country be specified at the start of the database search? If so, which countries should be chosen and prioritised? If I use a nested approach where previous searches feed into the next step, how can a systematic bias be avoided? What kind of criteria must be used to decide on a case study or paper or topic? Should multiple such searches be conducted for each country, type of technology or stakeholder? How can a feasible process be developed given the time and logistical limitations?

The grey literature search methodology search strategy that was used by Godin et al. (2015) proved useful for the review. Grey literature refers to documents such as government reports and theses which are not commercially published (University College London, n.d.). While the methodology was developed to predominantly find medical literature related to a specified case study, an adaptation of the strategy would allow us to find relevant case study-related literature in an exhaustive and comprehensive manner.

Some of the key tenets of this method included the use of custom google searches, grey literature databases and developing inclusion and exclusion criteria as well as an auxiliary survey of experts in the field. These were combined to create a relatively unconventional but effective literature search strategy suited for a review (Godin et al., 2015).

Firstly, prior to testing out sub-strategies for the literature search process, a general frame had to be visualised to allow for a sense of orientation and direction. Hence, a backwards approach was taken to develop this skeletal framework. This backwards approach essentially aimed to answer what steps or information was required to reach a certain stage in the literature search process. Thus, it began with a 'target' final state and worked itself backwards to our starting state.

The final state that is to be achieved in this process is the summary and review of the specific case study. Prior to that, a case study must be identified as having the potential to be reviewed and showcased as a best-practice. Thus, a list of all potential case studies appears to be the starting state of this literature search. However, given the sheer volume of literature available, an intermediate step was created for ease of developing the methodology. From the potential list of all case studies, a smaller pool of case studies with better potential to be best-practice cases will be selected. Thus, the literature search will be divided into three distinct phases: Firstly, narrowing down from all potential case studies to a smaller pool of potential best-practice case studies. Secondly, narrowing down to a single case study from this pool of potential case studies. Finally, the actual grey and academic literature search to generate the summary and review of a given case study.

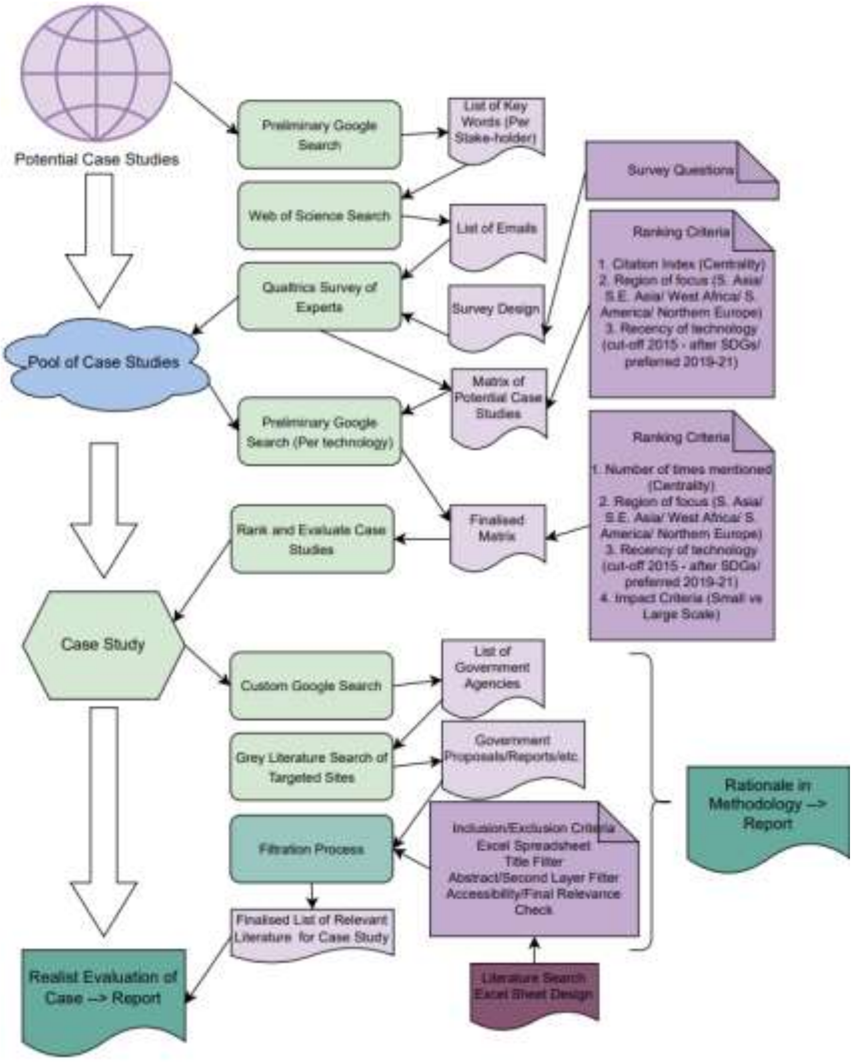
The first step involved narrowing from all potential case studies to a pool of case studies. In general, at this stage using commercially published 'white' literature is a good option to understand what current research focuses are. Thus databases such as Web of Science and Emerald Insights were identified as useful starting points. Multiple databases were used to ensure exhaustiveness as each database may have a slightly different set of publications. However, keywords are required to run searches in these databases. Thus, a preliminary google search of the relevant stakeholder's role and technologies in relation to each stage of the DRM cycle was conducted to generate a list of keywords. Google searches were also conducted to identify associated words or commonly used synonyms to the keywords to generate a finalised list of keywords. The search was then conducted on the database to generate a potential pool of case studies. However, integrating expert opinion at this stage would also be useful to check if the pool of case studies generated independently by this method matched with expert opinion. Thus, emails of researchers were identified from publications and an anonymised survey was created on Qualtrics for expert academics to suggest potential case studies. This is similar to the survey strategy as used by Godin et al. (2015). Finally, the resulting case studies from the database search as well as expert suggestions were integrated into a matrix of case studies.

To filter down to a pool of case studies, three major criteria were used: centrality, focus region and currency. Centrality refers to how central this case study or technology is in academic discussion. The more central a case is, the more it is written and discussed about. Citation indices thus become a useful numerical/ordinal indicator of this quality. Additionally, previous research and World Bank data has noted that the most vulnerable individuals to flood-risk are concentrated in the following regions: South Asia, East Asia, Southeast Asia, East Africa, West Africa, Northern South America and Northwestern Europe. These regions thus reflected our potential focus regions and case studies referring to these areas were given special importance in ranking and preference. Finally, currency refers to how recent the case study is. Flood-risk management has been a topic of civilisational importance since time immemorial. Thus, to review the status quo the most recent literature must be taken into account. Given that the Sendai Framework was released in 2015 and also because there was a noticeable increase in publications since 2015, only papers published from 01 January 2015 onwards were included. This filtration was used to rank case studies by potential for selection. After the ranking process, the abstracts of the paper were read to ensure their relevance. Non-relevant publications were thoroughly excluded from the list. Finally, the top ten cases were selected as the pool of potential case studies. This process was repeated for each stakeholder and stage combination for a total of 15 times.

The next step in this literature search process was to identify one case study out of the ten. Firstly, the main technology referred to in each case study was identified. A preliminary google search was conducted to gain a general background of the workings and application of the technology. After this process, the case studies were ranked on four criteria: centrality, focus region, currency and impact. The first three criteria were the same as in the previous ranking, and hence did not change the ranking of the list. However, the preliminary google search was fundamental in informing the fourth criteria impact. Impact in itself is a relatively broad term that could refer to the scale of impact or the target of an impact or general consequences of using a technology. The relative impact of technology after accounting for the scale of the intervention was considered as a measure of ranking. The more impact a technology has, the higher ranking it is given. However, this ranking was not easy to filter or rank based on ordinal or categorical data like the previous three criteria. Instead, a judgement call was taken to generate this final ranking. Subsequently, the top case study was picked as the final best-practice case study to conduct an in-depth review.

The final stage of the literature search involved identifying relevant documents and sources to conduct a review of the best-practice case study. Firstly a custom google search was conducted. Multiple search terms with various permutations and combinations were utilised to take advantage of the algorithm. Relevant articles would be bookmarked in a special folder to compile the resources. The results will be manually entered in an excel sheet to keep track of the sources. From these sources, a list of relevant agencies and actors will be identified for the case study. Target websites of these agencies/actors are identified and a search is then conducted within their databases or specialised search engines. Similar keywords to the custom google search are used to generate key documents. All identified documents are then listed on an excel sheet to undergo a filtration process based on some inclusion/exclusion criteria.

Documents are included based on their title, abstract/executive summary and overall relevance after skimming through the contents. The irrelevant documents will be excluded and the final list of literature will be saved in an excel sheet along with the URLs. In general, only accessible documents were considered for the purpose of the literature search based on the limited resources available. This list of relevant case study literature will be used to conduct the review of the case study. The evaluative criteria for each case study will be expounded upon in Section 1.4.



[***Figure 9***: *General Comprehensive Literature Search Strategy*[9]]

<u>1.2.2. Policy</u>

[9] Developed and illustrated by researchers based on methods outlined by Godin et al. (2015)

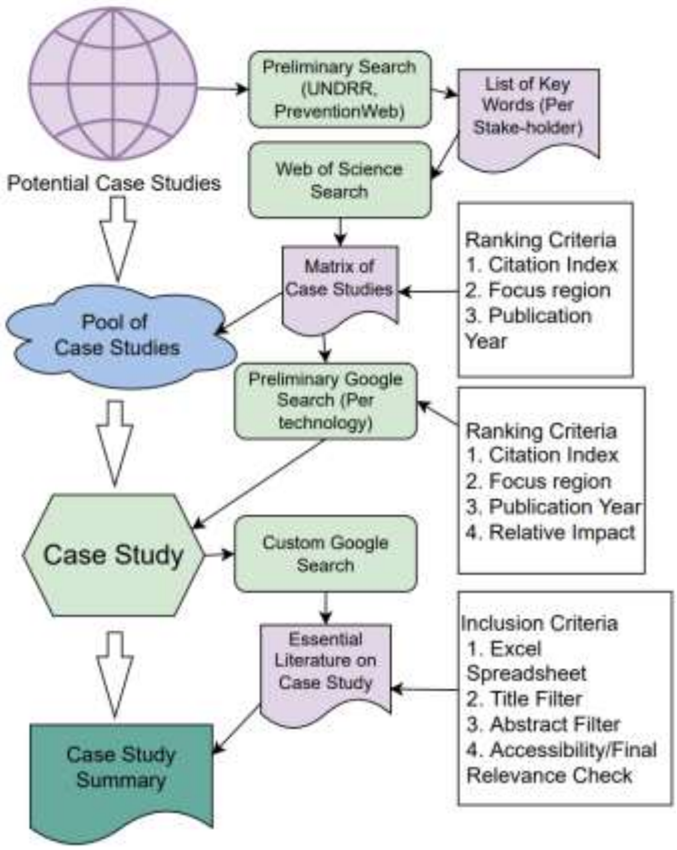
While a comprehensive methodology for the literature review was developed, it required a long time frame of around one year to actually implement. Within the period of 5 months that was available, it was simply not feasible to stick to such a rigorous standard if the review was to be conducted in time. Hence a few strategic simplifications to the methodology were considered to create a relatively comprehensive literature search strategy. This simplified strategy was used for the public sector. The strategies used for social and private sector literature searches will be explained in the following sections.

Firstly, a simple preliminary search in select target sites such as the UNDRR website and PreventionWeb was conducted to generate a list of keywords for the public sector in each stage. Secondly, only one database was used to generate the matrix of potential case studies. Due to its interdisciplinary nature and wide array of available publications as well as ease of use and export of data, Web of Science was used to conduct searches. Thirdly, the resultant matrix of case studies still underwent the same ranking process as described in the previous section. Fourthly, a survey was sent out for researchers involved in flood-risk management in the public sector to identify useful case studies. This boosted the search saturation. These case studies were also included in the above ranking process and a final pool of 10 case studies.

The second stage of the literature search process was also simplified. As mentioned previously, a preliminary google search was conducted for each technology to gain a better understanding of its function and application. However, instead of undergoing a second ranking, a judgement call was taken based on the 'impact' criteria explained in the previous section.

Following the selection of the case study, the following literature search was simplified to a custom google search and occasional search of target sites where it proved necessary. This was to ensure that relevant literature was found quickly despite sacrificing exhaustiveness of the process. The inclusion/exclusion criteria were then applied to the listed literature to generate a final list of literature for the case study.

Overall the simplifications ensured that the literature search strategy was indeed feasible to conduct in the short span of time and within the limit of the resources available to the researchers. While the search was markedly less rigorous and exhaustive, it still generated a relatively comprehensive list of useful literature for each case study.



[***Figure 10***: *Simplified systematic Literature Search for the Social sector*[10]]

1.2.3. Society

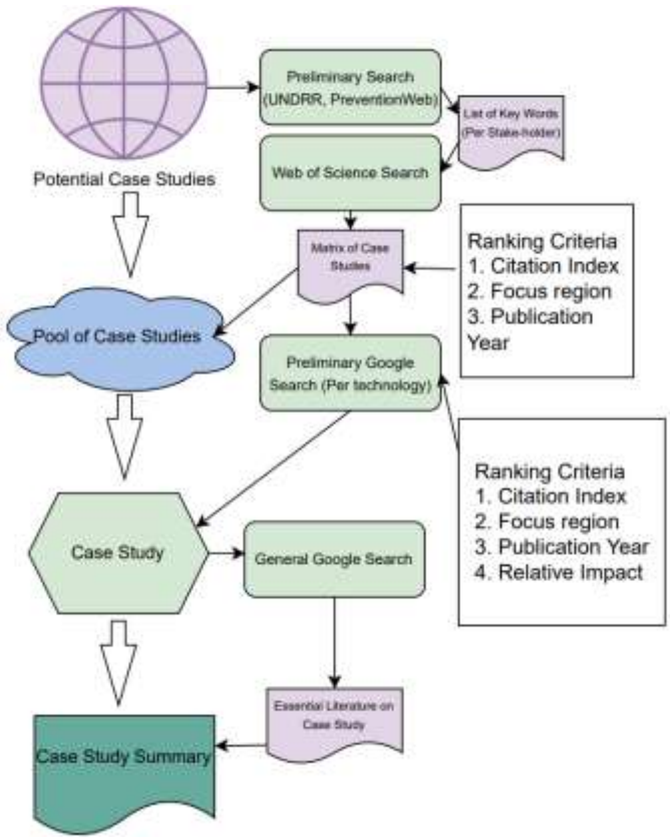
The search strategy for the social sector is almost identical to that of the public sector. The only change was that the final section of the literature search was simplified due to insufficient academic sources. A simplified google search replaced the initial custom google search.

Firstly, during the initial stages of the literature search a large volume of academic studies on social resilience and literature on frameworks were available. However, there were relatively fewer case studies or ethnographies identifiable. The literature was still ranked and possible technologies or socio-technological solutions were identified and further ranked by their relative impact on resilience.

The custom google search was however used to identify potential case studies or organisations that were involved in a recent flood disaster. This was a relatively less organised process and on occasion some case studies were found using a non-structured google search rather serendipitously.

[10] Developed and illustrated by researchers

Finally when gathering documents and evidence for building the case study, the inclusion criteria has to be relaxed. The reason was that, more often than not, literature for the specific case study was scattered across various types of publications ranging from UN reports, NGO reports to news articles and NGO websites. Therefore, this evidence had to be supported by generic reviews or reports on the technology to build a case. This is where the approach for the social sector diverges significantly to that for the public sector in terms of the utilisation of literature.



[***Figure 11***: *Adapted systematic Literature Search for the Social sector*[11]]

1.2.4. Private

For the private sector, the lack of formal academic literature led to an adapted systematic strategy: Initial keywords were still based on the conceptual framework and refined and extended through a google search. The selected keywords were then used to conduct a semi-structured search in databases and websites. The following three ways through which a pool of case studies was identified was:

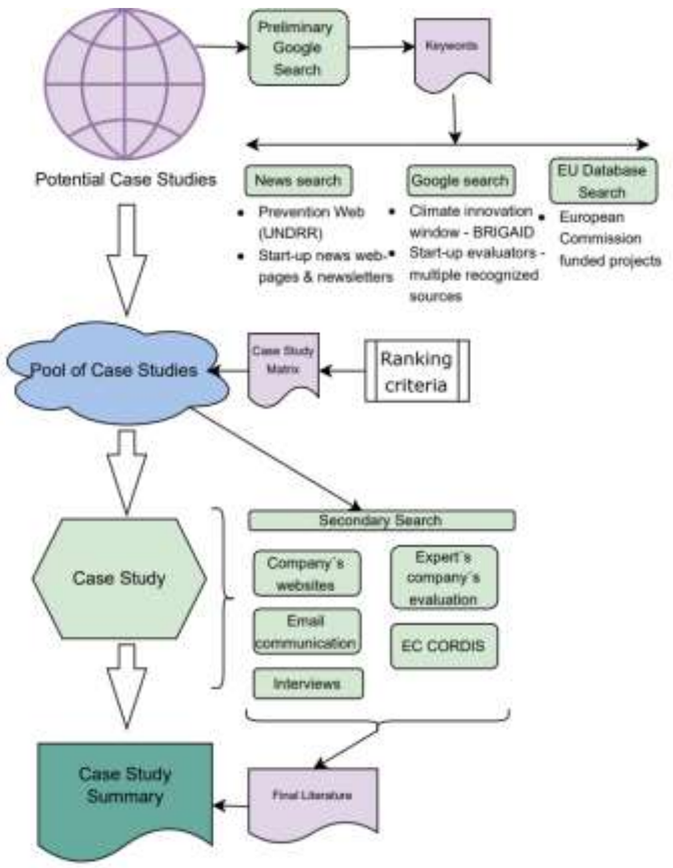
First, a news search in Google, a news search in the Prevention Web of the UNDRR and a news search in several start-up focused online magazines and start-up (news) websites.

Secondly, a Google search encompassing myriad other resources that identify Entrepreneurs and Start-ups in the flood disaster risk management sector was conducted. During a preliminary Google search, the researchers found the Climate Innovation Window, which was developed under the frame of the BRIGAID project. The BRIGAID project, in turn, was a project funded under the EU Horizon2020 that aimed to “bridge the gap between innovators and end-users in resilience to floods, droughts and extreme weather.” The project was implemented from 2016 to 2020. The Climate innovation window subsequently was a reference portal to connect these stakeholders - it hence had immense value in identifying innovators - so also Entrepreneurs and start-ups for this review (BRIGAID, 2020).

Thirdly and finally, a search in EC Databases was conducted since many successful start-ups were originally funded by the EC. This included mainly the EU and EC Databases like CORDIS, which publishes EU research results. The results of projects funded under European Horizon2020 were published here, for example (EC, n.d.).

After identifying a pool of potential case studies, a search of each case with a different strategy was carried out based on the nature of the case study. For example, one company had an elaborate website, whereas another was funded by the European Commission and hence had published material on the EU databases. Another company was founded by private Entrepreneurs and had very informative material on their website. For other companies, an expert evaluation was available, like the IEAMA Sustainability Award of the Solar Impulse Foundation or the previously mentioned Climate Innovation Window platform. Finally, email communication and interviews with involved actors in the Start-ups prove most helpful in accessing information that was not available on the Web. This Final Literature was compiled to generate a Case Study Summary.

[11] Developed and illustrated by researchers



[***Figure 12***: *Adapted systematic Literature Search for the Entrepreneurship/Start-up sector*]

6.3. Assessment Framework: Evaluative Criteria

After the identification of best-practices, they had to be evaluated. Given that the powers and interests of each sector differ, a unique set of evaluative criteria had to be developed for each stakeholder sector.

Since this research has identified its review question to represent a complex phenomenon, the conventional establishment of exclusion and inclusion criteria for the review and synthesis is complicated. In this case, the quality and relevance assessment can only occur later in the methodological process as they are an integral part of the process or reviewing the relevant literature and require sophisticated knowledge about what makes technology a best practice for respective stakeholders in the complex field of disaster management. Such a delayed identification of quality and relevance assessment is, however, not uncommon in the social sciences research (Gough, 2007; Higgins et al., 2006; Template University University Libraries, 2022).

However, the researchers still wanted to lay a foundation for an assessment for easier and more efficient beginning of the next stage in the next period but also to get valued feedback on this complicated research endeavour of establishing generic and content related criteria. Hence, besides establishing generic criteria of quality in both qualitative and quantitative studies, a preliminary assessment of best-practice criteria is outlined in the next section.

Concerning generic quality criteria for quantitative studies and qualitative studies is also a difficult endeavour considering the complexity of the studied phenomena and the lack of rigorous methodological reflections in many studies. Furthermore, since this review and synthesis is drawing from both research studies and official reports or websites, methodology sections are often scarce and especially in qualitative papers, a certain lack of scientific rigour can be identified (Caelli et al., 2003).

However, generic criteria will be oriented towards high quality to provide reasonable assurance to related stakeholders that the underlying literature of this review and synthesis are reliable. This relates to a clarity of purpose (transparency), accuracy, accessibility, and method specific quality (specificity) (Gough, 2007).

6.3.1. Policy

Policy in relation to disaster risk has a very broad outlook due to its interdisciplinary nature and social/political/economic context. There are various government regulations which range from building safety standards, volunteer management, partnerships with organisations and public education. They address various types of man-made and natural disasters. Such disasters involve large economic costs as well as societal risks which could also strongly affect political outcomes. It is also crucial to consider the various levels of government which range from local to provincial/state to national levels which may have different priorities and focuses. Any policy instituted at any level of government needs to be efficient and effective. Additionally given the difficult situation of any disaster, there will be ethical standards to maintain as well. Finally in practical terms a policy would also need to be financially and administratively feasible (Waugh, n.d.).

The effectiveness of a policy is defined by how likely the objectives set will be achieved. This includes cost-effectiveness where the output given the cost is considered. Efficiency looks at the benefits of a policy in relation to its cost and typically involves some kind of cost-benefits analysis to determine if a policy is ‘worth it.’

The administrative feasibility considers the capabilities, responsibilities and resources of the government agency delegated to implement a policy to assess its ability to implement. Financial feasibility looks into the availability of funds and resources to invest in a policy and the extent to which costs can be recouped. Ethics is a complex evaluative criterion which involves both equity and liberty.

Equity is concerned with the distribution of the benefits and costs of a given policy. In the setting of disaster risks, it would also consider the existing distribution of risk across society and ideally reduce the risk for all citizens rather than redistribute existing risk more evenly. Liberty covers the notion of individual rights and choices and to what extent does the policy ensure these rights can be exercised or restrict them (Kraft & Furlong, 2020).

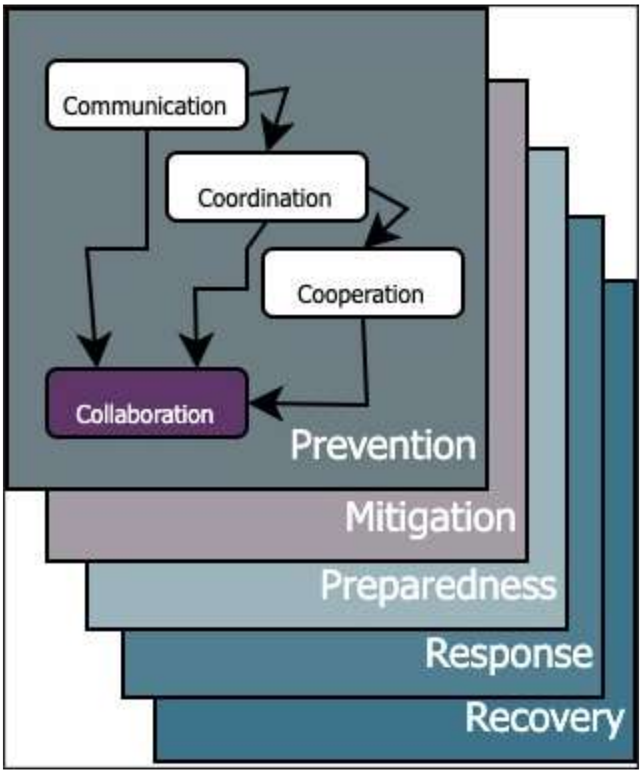
Scientists play a role of policy-advisors to policymakers. There is a juxtaposition of time available between the policy domain and science domain. Many policy analysts need to react quickly to disasters while scientists often require more time to ensure thoroughness of findings. There needs to be more holistic risk assessments that account for social and economic impacts of a hazard. Scientists/experts need to be increasingly trained in this new paradigm of disaster risk assessment. Many policies fail due to poor transfer of knowledge between scientific circles to the general public. There is insufficient investment in disaster risk research due to constrained resources and finances. Furthermore, a lack of platforms for researchers and practitioners to interact leads to a poor transfer of knowledge and possible divergence in epistemological/paradigmatic approaches (Albris et al., 2020).

In summation, the three criteria are cost-effectiveness, feasibility and equity.

6.3.2. Social

Disaster risk affects all members of society, and social organisations as well as individuals contribute to all stages of the DRM. Social/humanitarian organisations such as Red Cross act as providers of emergency care immediately post-disasters in the response and recovery phases. They also play a role in alleviating disaster response burdens across local divisions. When a local division is overwhelmed, other divisions are quick to assist and provide support. Access to accurate information plays a crucial role in the collaboration of individuals and local organisations during all stages of the DRM. This improves preparedness, volunteer retention and response efficiency (Troy et al., 2008). The relevance of a given piece of information changes depending on the actor and the level of action (local or national). Most often, information is generated and used during the response and recovery phases rather than the other three, limiting its potential positive impacts in reducing disaster risk. The efficacy of a technology will depend on the extent it can replace manual labour such as land-use change and climate anomaly identification which are time consuming processes (Enenkel et al., 2017). Beyond just being sources of information, technology also becomes an enabler of resilience. This includes aiding response and preparedness efforts. This enconmpasses setting up an operating temporary/alternative infrastructure and using social media as a tool to direct relief efforts as well as ensuring sufficient coverage of an early warning system (de Meira & Bello, 2020).

Given the nature of the relationship between DRM, society and technology, a distinct set of evaluative criteria are required to analyse and evaluate best practices. The A3C model appears to be particularly useful. This model evaluates technology based on their ability to facilitate communication, coordination, and cooperation. Communication is the sharing of information between a sender and receiver. This also means the receiver should be prepared to receive and act on the information. Coordination involves managing the dynamic contributions of various actors and agencies when addressing any response to DRM. This takes into account any resource constraints, capacities and evolution of events. Effective communication becomes a prerequisite for efficient coordination. Cooperation is defined by how various actors/agencies/entities act together towards a common goal or for a shared purpose. Efficient coordination is therefore essential in ensuring proper cooperation. All the aforementioned factors, namely communication, coordination and cooperation are required for collaboration. Henceforth, collaboration is seen as a composition of these services. As collaboration plays a key role in successful DRM at every stage of the cycle, a technology would be judged by its ability to improve communication, coordination, and collaboration at a social level (Simona et al., 2021).



[***Figure 13:*** *Visualisation of A3C Model for Social Sector Criteria (Simona et al., 2021)*]

6.3.3. Entrepreneurship/Start-up

Before explaining and justifying the criteria for this stakeholder section, it must be justified why, in contrast to the Public and Civil Society sector, not a case-study in the conventional sense but rather a company is used.

The key logic behind this decision was that every technological application is evidently highly context-dependent. One technology developed by one company, applied in one location for certain customers, can have completely different benefits and drawbacks than the same technology being applied in another context. However, the aim of this review is to identify and explain meaningful best practices that Entrepreneurs or those aspiring can clearly identify within multiple contexts. Also, every start-up has a unique backstory and entrepreneurial journey that a review focused on the technology could showcase. Hence, essential insights for those who want to learn from the best practices of others would be lost.

The second aim of this review in the context of Entrepreneurship/Start-up evaluation is that the best and most promising partners for collaboration shall be identified. Granted, looking at one technology as applied by multiple companies/start-ups would be the most comprehensive and give the best overview. However, the scope of this review does not allow such an enormous undertaking. Rather it wants to focus on evaluating the best start-ups and how they applied their technologies.

Given this justification for evaluating the individual company and in that context, the technology, the following paragraph will lay out how the criteria were defined.

[***Figure 14***: *Visualisation of Entrepreneurship/Start-up Criteria*]

The private sector is the starting point of new innovation and, subsequently, sustainable change. Hence, a unique focus was laid on the innovativeness of the respective technologies. Innovation means being creative in redefining related problems and seeking out new opportunities. This is essential in developing or improving novel technologies that can increase resilience. Innovative technology is original, effective and often revolutionises the way that the underlying problem it aims to address can be tackled. Innovation does not happen via predetermined paths and cannot arise in isolation, and is characterised by feedback among stakeholders and reciprocity. The private sector, more so the Entrepreneurship and start-up sector, often faces immense pressure to innovate to stay competitive or use non-conventional methods to achieve a competitive edge or create new markets (Guerriero & Penning-Rowsell, 2020; Inter-Agency Standing Committee, 2019). Key questions that will guide the Innovation sections of the best-practice case studies are: How is the technology developed by the company different from others, and how is it different to existing solutions to the underlying challenge? What is this start-up´s technology´s merit that other technologies cannot deliver? How did the technology progress flood risk prevention, mitigation, preparedness, response and recovery? How did it use non-conventional/novel solutions to address issues in challenging areas of flood risk management?

Innovation is not only essential as a stand-alone criterion used by many expert evaluations, but it also lays the foundation for profitability, cost-effectiveness and impact creation. Without being innovative, a start-up cannot scale. It would be very difficult to find networks, collaborate or attract new clients if the solution is not different to that of the market. In that way, innovation is the essential building block in achieving long-lasting profitability for a company.

Concerning profitability, several aspects shall be covered under this criteria: How is the company financing itself? Who are investors, and how high are investments? At which stage of commercialisation is the company, and what stage is reachable in the foreseeable future? While these are important questions to be answered, the profitability of a start-up´s technology for its clients must also be considered. Hence, a stark focus on the Return on Investment for the client will be considered. This includes prices for the different clients and how cost-effective the solution is for them. Is the best-practice technology affordable? Can a certain monetary investment in the technology achieve a reduction of costs when a flood disaster occurs? Are implementation and maintenance affordable? Is the technology perhaps more cost-effective than others on the market?

Given a certain level of innovation that fosters profitability for the company and customer, the final and essential criteria concern the human impact the technology can create. How does the technology (have the potential to) impact many stakeholders? How can it provide real resources/solutions/benefits that the most vulnerable in society require when flood disasters occur? Can the technology attract inclusive stakeholder engagement? Does it have the potential to be replicable to be applied to contexts outside its original location? Can it impact many more people when scaled? Does it create benefits across a range of sectors and disciplines? For example, through efficient use of data or resources that are quick and inexpensive?

An Entrepreneur that scores high on all these criteria with the technology developed in their start-up can be said to score very high on multiple-value creation that has at its utmost goal the increase of resilience against flood disasters.

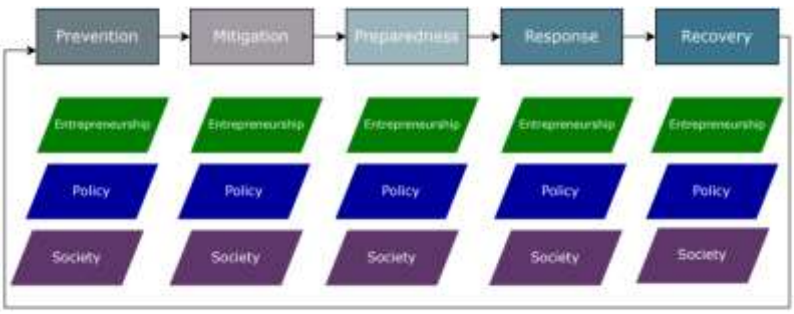
The following graphics have been created by the researchers to give the reader an overview of the case-studies and criteria.

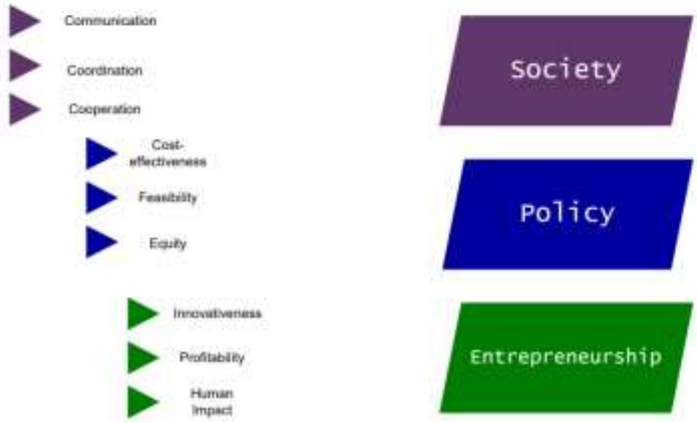
[***Figure 15***: *Case-study Matrix Output & Criteria for each Stakeholder*]

6.4. Interviews

They explored the barriers and expectations of stakeholders. To ensure concurrent flexibility, a semi-structured approach was preferred. Similar to the reviews, the interview guides were specifically formulated for each type of stakeholder. Later they were uniquely adapted to each interviewee based on their profile and experience to focus on their expertise within the scope of our questions. The questions were themselves based primarily on the conceptual framework and our second research question. The transcriptions underwent a thematic analysis to arrive at key themes which we shall visit in the conclusion.

Given the qualitative nature of this aspect of the research, a constructivist paradigm was considered. In such a case, the discussion is around expectations, barriers, challenges and emerging solutions. These are formed and perceived by the stakeholder based on their interactions with the reality of structural measures, non-structural measures as well as other stakeholders. Thus, it is observable that these perceptions of the tangible, real world are constructed by stakeholders. Further narrowing down this approach, interpretivism and phenomenology





become useful tools. Interpretivism emphasises the interpretation of the real world through classification schematics within an individual's mind. Given the above, a phenomenological paradigm is useful due to its emphasis on a socially constructed reality and the individual's perception of that reality. The somewhat subjective nature of this means that the validity of an individual's viewpoint is not measured against some universal standard or common objective. On the other hand, the researchers seek this subjectivity to compare the views of different stakeholders to account for dissonance in perceptions and expectations. Overall, this approach interprets these expectations, barriers and emerging solutions as socially constructed and idiographic phenomena (Gray, 2014; Williams & May, 1996).

In general, this part of the research is also more exploratory as it aims to uncover these perceptions and deconstruct or organise them to ensure applicability to the real world. Therefore, an inductive approach is used. This can be achieved by making use of open ended questions. Such an inductive approach permits the researcher to conduct a thematic analysis to identify useful concepts and themes across a variety of interviews. These are then framed as barriers, expectations and emerging solutions. It is important to note that this research provides a cross-sectional viewpoint rather than a longitudinal study, although there is potential for such extension (Gray, 2014).

Given the broad scope of this study, a targeted sampling strategy was utilised. Over the course of the literature review and general research process possible 'high-value' individuals were identified. These persons could be academicians, members of an established private or public institution, start-up founders, social entrepreneurs and civil society actors including personnel from NGOs. Potential individuals were identified based on their involvement in flood risk management. The basis of inclusion in the list depended on their expertise. Academicians were chosen based on their publication history and focus, members and consultants in large private or public sector firms were chosen based on their personal experience and previous experience. Entrepreneurs and social actors were chosen based on the technology they developed or their organisational affiliation. A snowball technique[12] was also occasionally employed where target interviewees were asked to suggest other organisations or people to interview (Gray, 2014).

In total 11 individuals were interviewed of the over 60 individuals contacted over the course of 2 months. The interviews were semi-structured and anonymised to ensure all information management laws were followed. Interview guides were used to ensure a consistent interview while also allowing flexibility to dive into different topics of discussion as required and based on the expertise of the interviewee[13].

For the purpose of this report interviewees were given a unique ID to cite any useful comments or data revealed through thematic analyses. The codes assigned also categorised interviews based on where they fit in the stakeholder schematic used in this report. However, if an individual fit into two categories, that was also taken into account. It is important to note that this categorisation provides a general overview of their space of operation and scope, but not necessarily their insights. More often than not, insights about the social sector were often derived from public and private sector interviews due to previous experiences working with civil society entities. If an individual was unavailable for an online or physical interview, email correspondence was also used. Interviews were audio recorded and transcribed. The interviews were conducted entirely in English. Email correspondences were conducted in English, German and Tamil[14]. The consent form[15] was also translated into Tamil to aid response from civil society members. The summary of interviewees is available below:

S/N	Affiliation	Stakeholder	ID
1	Radboud University	Public	PUB01
2	Royal Haskoning DHV	Private+Public	PAP01
3	Homa Reto	Private	PVT01
4	Leiden University	Public	PUB02
5	Aquobex Technologies	Private	PVT02
6	CODATA-Germany	Public	PUB03
8	HKV Consultant	Private+Public	PAP02
9	Sustainability.io (Flood warning prototype)	Private	PVT03
10	Civil Society Member (Chennai, India)	Social	SOC01
11	Climate Campus (Zwolle)	Social	SOC02
12	Deltares Engineer	Private	PVT04

[12] Refer to Appendix C
[13] Refer to Appendices D, E and F
[14] Refer to Appendix G
[15] Refer to Appendices A and B

[***Figure 16***: *Anonymised Summary Table of Interviewees*]

The analysis of the transcripts and correspondence were done using the thematic analysis technique developed by Braune and Clarke (2006). Firstly, the interviews were transcribed from an audio to a text format. The interviews and email correspondence were then assigned codes as part of the coding process. Codes were assigned to reflect patterns in the data or topics of similar nature and would be useful for the next step. The coding was coordinated between researchers to ensure a common protocol was followed. Coordination occurred by using a system of comments on transcripts on a common shared drive. There was a high level of inter-coder reliability ensuring consistent coding across interviews.

Following the completion of the coding process, an initial set of themes and concepts were identified. The themes were then reviewed and overly complex themes were broken down into smaller sub-themes for ease of analysis and discussion. Finally, these themes were categorised as either barriers, expectations or emerging solutions and summarised in a table to aid the discussion of the findings (Braune & Clarke, 2006). The findings will be revisited in the discussion and conclusions sections of the report.

Best-Practice Solutions
Viridian - NBs modelling
Innovation
Profitability
Human Impact
Prevention
Mitigation
Preparedness
Response
Recovery
Bufferblock - Drainage
Innovation
Profitability
Human Impact
Prevention
Mitigation
Preparedness
Response
Recovery
FloodMap - Satellite Data
Innovation
Profitability
Human Impact
Prevention
Mitigation
Preparedness
Response
Recovery
i-React Multi-stage system
Innovation
Profitability
Human Impact
Prevention
Mitigation
Preparedness
Response
Recovery
Homa Reto - Participatory Mapping
Innovation
Profitability
Human Impact
Prevention
Mitigation
Preparedness
Response
Recovery
Diversion Canal, Detention Tank
Cost-effectiveness
Feasibility
Equity
Prevention
Mitigation
Preparedness
Response
Recovery
Rain Gardens
Cost-effectiveness
Feasibility
Equity
Prevention
Mitigation
Preparedness
Response
Recovery
Flash Flood SMS Warning
Cost-effectiveness
Feasibility
Equity
Prevention
Mitigation
Preparedness
Response
Recovery
Unmanned Aerial Surveillance
Cost-effectiveness
Feasibility
Equity
Prevention
Mitigation
Preparedness
Response
Recovery
Bioswales
Cost-effectiveness
Feasibility
Equity
Prevention
Mitigation
Preparedness
Response
Recovery
Lake and Tank Restoration
Communication
Coordination
Cooperation
Prevention
Mitigation
Preparedness
Response
Recovery
CATCH pilot Zwolle
Communication
Coordination
Cooperation
Prevention
Mitigation
Preparedness
Response
Recovery
Functional Estimation System
Communication
Coordination
Cooperation
Prevention
Mitigation
Preparedness
Response
Recovery
Volunteer Flood Mapping
Communication
Coordination
Cooperation
Prevention
Mitigation
Preparedness
Response
Recovery
Cash Transfer Systems
Communication
Coordination
Cooperation
Prevention
Mitigation
Preparedness
Response
Recovery

Viridian - NBs modelling

Prioritisation of most effective and efficient NBs for a given problem cannot be created using standard techniques

Innovation	Profitability	Human Impact
IEMA Sustainability Award *"Highly innovative modelling system ... great progress in the planning"*	Cost-benefit 1:30 - quick and inexpensive to attract stakeholder engagement and maximising ROI	• Delivers real benefits to many • Affordable solution even for small organizations and NGOs • Flexible & inclusive design

Prevention Mitigation Prepardness Response Recovery

Bufferblock - Drainage

Development of stormwater catchment blocks installed beneath the road in urban areas to store & redirect water

Innovation	Profitability	Human Impact
Bufferblocks combine maximum space for water with high stability - making it a simple yet efficient solution	Cost-effective in installation: stability means thinner top layer & easy in maintenance, myriad benefits	Alleviates the impact of floods, especially from stormwater for urban areas, hence has the potential to create immense value

Prevention Mitigation Prepardness Response Recovery

FloodMap - Satellite Data

Highly accurate flood forecasting, real-time flood monitoring and water levels available right after flood

Innovation	Profitability	Human Impact
"DASH combines traditional engineering approaches (hydrology) with cutting edge science & technology"	Profitable for public procurement and private sector, near real time satellite data that was not available before	*"Delivers dynamic flood intelligence with live updates that can scale from street level to national views"*

Prevention Mitigation Prepardness Response Recovery

i-React Multi-stage system

Multiple-Source Data collection and distribution incorporating civil society for real-life response action

Innovation	Profitability	Human Impact
"Next-generation multi-hazard early warning system - ahead of marketplace at development stage (Member i-REACT).	Prices professional app & wearables per user per month (€5,- /€10,-) Social media App /system/month(5.750,-)	Focus on developing world &SIDS as most at risk of natural hazards & weakest early warning systems and citizen engagement

Prevention Mitigation Prepardness Response Recovery

Homa Reto - Participatory Mapping

Organizational tool for civil society employing participatory mapping - web-based and mobile application

Innovation	Profitability	Human Impact
One of the very first tools organizing civil society - New way to include Volunteers and Civil Society - Inclusion instead of extraction	Highly convincing message that is motivating for a volunteering team, cost-effective and highly affordable for potential users	Innovative and inclusive to generate real benefits of the most vulnerable and flatten hierarchies, gain visibility and agency

Prevention Mitigation Prepardness Response Recovery

Viridian - NBs modelling

NBs/Engineered solution

Development of modelling system HydroloGIS, capable of finding the optimal Nature-Based solution for a given problem

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description

- Prioritisation of most effective and efficient NBs for a given problem cannot be created using standard GIS or hydrological models
- Conventional NBs projects have a failure rate of 50%
- HydroloGIS can stop this failure and take into account local constraints like agriculture, pollination or recreation

Innovation

Awarded IEMA Sustainability Impact Award 2020

"*Judges felt it was a highly innovative modelling system that had made great progress in the planning and improvement in natural catchment management – a usually challenging area*"

Profitability

- Cost-benefit ratio of NBs project modelled **1:30**
- Efficient data usage - quick and inexpensive to attract stakeholder engagement and maximising ROI
- currently at small-scale commercialization

Human Impact

- Delivers real benefits to many stakeholders
- Affordable solution even for small organizations and NGOs
- Flexible & inclusive design; greatly reduces consultation times
- Highly replicable to generate maximum impact

Challenges, Solutions & Scaling

- Small-scale commercialization: identified over 3000sqkm of natural interventions to solve local problems
- No news on large-scale public procurement/public funding
- However, successful collaboration with Climate Innovators Network & Ambiental Risk Analytics - Fruitful collaboration & increased visibility could lead to immense scaling: "*Intelligent use of natural solutions crowds-in funding for nature, potentially unlocking $billions*

Review Overview

Taking into account that for the Entrepreneurship/start-up sector, both the technology and the company will be reviewed in tandem, as argued to provide meaningful insights to readers of this report - the following structure was created for the Entrepreneurship/start-up sector. First, a review of relevant (emerging/new) technologies in the respective stage concerning the private market will be given. This shall give the reader a broad overview of which technologies are most discussed in the respective stage. This will also provide relevance and context to better position the selected company with its technology in the respective stage. Inherently, a justification of why the given company was selected will be given in this preliminary section. However, the in-depth analysis of the company follows after the explanation of the technology in the evaluation section. Finally, Challenges, Barriers and Expectations will be presented based on relevant literature or primary research in the form of Interviews.

Having given the structure that the review of the Entrepreneurship/start-up sector will follow, a brief introductory summary of the stage reviews will be given. In the Prevention stage, both engineered and Nature-Based solutions (NBS) will be considered. However, a stark focus will be laid on NBs modelling since there is a major gap in those technological solutions in the market that the private sector can potentially close. Feedback loops shall be discussed together with the case studies in these stages in the discussion section. For the Mitigation section, an in-depth focus on engineered solutions will be given. However, since the review excludes large corporations like Royal Haskoning, niche solutions, particularly in the urban drainage sector, will be considered. This concludes the Entrepreneurship/start-up review in the structural first two stages of the Disaster Management Cycle.

Following will the Disaster Management stages of Preparedness, Response and Recovery. Inherent feedback loops make a differentiation between the stages difficult in terms of placing the respective company´s technology in a certain stage. The researchers will therefore include a section on Feedback loops for each company´s technology to explain the interconnectedness of the stages in this stakeholder sector. In the Preparedness stage, early warning systems will be reviewed. This shall include largely successfully scaled companies and small start-ups with a social mission and creative solutions to difficult problems. Given that, as in the market analysis section explained, satellite technology has emerged as one of the most prominent and promising new technologies, a special focus will be laid on it. However, given that this industry is profit-driven, a non-satellite technology will be chosen, which can provide similar benefits but has a societal mission at heart.

For the Response stage, a multi-stakeholder cyber technology project will be reviewed that summarises key aspects that an inclusive platform can possess.

Finally, the Recovery stage will briefly review large upcoming technologies in the sector before choosing a niche company that has immense potential but still lacks visibility and monetary challenges for scaling.

1. Prevention

1.1 Nature-technological solution

1.1.1. Relevance & Context

NBs are “actions to protect, conserve, restore, sustainably use, and manage natural or modified … ecosystems, which address social, economic and environmental challenges effectively and adaptively ” (NBs Initiative & University of Oxford, 2022). Case studies from across the world, as well as an increasing amount of scientific literature, point to the successes of NBs being used to manage flood risks sustainably (Endo et al., 2022; NBs Initiative, 2022). Authors of prior academic literature and case studies, as well as interviews for this research project, emphasise the importance of using NBs within a comprehensive, inclusive strategy of flood risk management (PAP01, PUB02, PAP02; Endo et al., 2022; NBs Initiative, 2022; Lallemant et al., 2021).

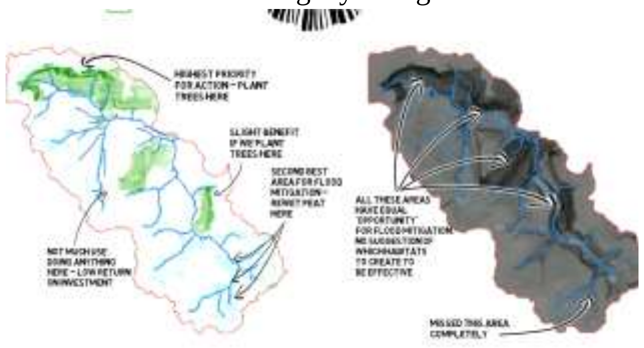
When planned and implemented correctly, NBs can bring myriad benefits in preventing floods while protecting or even enhancing local ecosystems (Endo et al., 2022; Viridian, 2021). According to a recent report from NB case-studies in the Philippines, Endo et al. (2022) from the Asian Development Bank concluded that “NBs enable decision-makers to choose from a wider range of hybrid solutions instead of being limited to either grey or green options. They are adaptable and can complement traditional grey infrastructure”. This has also been the expert opinion of several public and privately employed engineers from the North-Sea Region and Italy (PUB01, PUB02, PUB03, PUB05). However, “a lack of well-recognised standard methodologies to evaluate their [NBs] performance and upscale their implementation remain” (Kumar et al., 2021).

In a recent review of modelling methods for efficiency evaluation of NBs against natural hazards, Kumar et al. (2021) conclude that modelling systems that can assess the diverse range of benefits and implementation complexities of NBs are crucial to facilitate impact assessment and hence accelerate their adoption. Viridian´s modelling system is one such modelling system capable of holistically assessing the multiple benefits of NBs through e.g. a cost-benefit analysis.

1.1.2 Difference to other technologies:

The technology that Viridian Logic has developed is a new modelling approach for identifying the most efficient NBs to mitigate or prevent floods (Viridian, 2021).

Conventional methods of finding NBs are either hydraulic modelling or GIS map overlays. Both are often suboptimal in identifying the most efficient and effective NBs for flood risk management. Both methods are not holistic models and do not integrate a cost and benefits analysis (Kumar et al., 2021; Nelson et al., 2020; Viridian Logic, 2017; Solar Impulse Foundation, 2021). Figure 1 depicts the fundamental drawback of GIS modelling on the right: It merely shows the areas which have the right characteristics whereby NBs should alleviate flooding. In comparison to the modelling of the same problem under modelled with HydrologGIS to the left, GIS modelling is unable to indicate which location will increase the chance of alleviation of flooding by a high likelihood. It also



[***Figure 2***: *Conventional hydrological modelling (right) and Viridian modelling (left)(Viridian Logic, 2017)*]

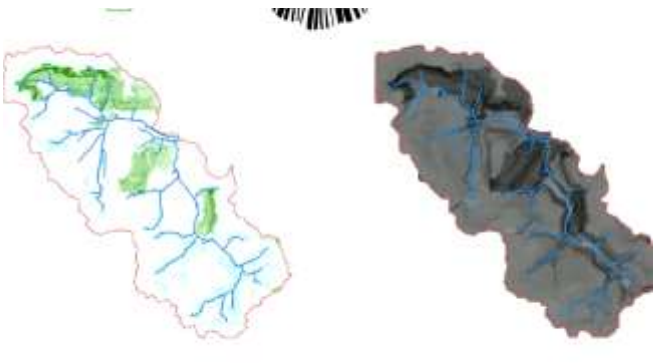
1.1.2 Working of HydroloGIS:

First, water flow across the landscape is determined. Secondly, a modified version of the universal soil loss equation is employed to determine the interaction between the water flow and physical landscape. With the formula, the transport and accumulation of water on every five meter square or pixel across the catchment is calculated.

The third step then includes how nature plays into the equation. The vegetation and land use for each pixel is modelled. The model calculates how land and vegetation interact with the flow path of the water.

Through these three steps every pixel is ranked in how much it contributes to reducing flooding, as well as

cannot prioritise one solution over another (Viridian Logic, 2017).



[***Figure 1***: *One area of land modelled with hydraulic modelling (on the right) and with HyrdoloGIS from Viridian Logic (on the left) (Viridian Logic, 2017)*]

Viridian's model, HydroloGIS, on the other hand is able to unite the “sophistication of hydraulic modelling with the robust simplicity of meta-analysis, to show exactly which NBs to create and where to create them to most reduce flooding and maximise return on investment” (Viridian Logic, 2017). Figure 2 below shows a case-study example of the difference in real decision support output of the two models.

how high it´s potential is to reduce flooding through the implementation of NBs (Viridian Logic, 2017).

1.2 Evaluation

1.2.1 Innovation

Viridian´s modelling solution HydroloGIS has been awarded the innovation award at the IEAMA Sustainability Impact Awards 2020. “The judges felt HydroloGIS was a highly innovative modelling system that had made great progress in the planning and improvement in natural catchment management – a usually challenging area” (Viridian, 2021). Furthermore, the solution has been awarded the Solar Impulse Efficient Solution Label one year later; experts conclude that “HydroloGIS added value is unique” (Solar Impulse Foundation, 2021).

1.2.2. Profitability

Costs

Solar Impulse Foundation Efficient Solution Evaluation (2021), the base price for the HydroloGIS model lies at £10sqkm, or €11,60/sqkm. In comparison to traditional modelling or other models, this is a highly affordable solution for smaller organisations, small NGOs recovering from floods or any other small-scale civil organisation not able to afford cost-intensive modelling solutions.

ROI for customers

Modelling NBs, which will then be implemented, can be highly profitable for actors employing Viridian´s HydroloGIS. The cost-benefit ratio of a NBs project modelled by HydroloGIS is 1:30, and that is only under consideration of direct benefits. Furthermore, standard design techniques of NB projects have a failure rate of 50%, one of the factors leading to low adoption of NBs (see section 1.1.1.), HydroloGIS models NBs that guarantee success. Hence, the benefits that can be reaped from nature, among them climate resilience and subsequently flood resilience, are modelled with sophistication to provide solid and inclusive decision support. This information was adopted and extended based on the expert evaluation of the Solar Impulse Foundation which reviewed Viridian Logic in March 2021 in the realm of their 1000+ efficient solutions[16]. Viridian´s solution was furthermore awarded the IEMA Sustainability Impact Award for New Product, Service or Technology. Concerning ROI, the judges concluded that within the modelling solution, there "was an emphasis on efficient data usage, which was quick and inexpensive, to attract stakeholder engagement and maximise ROI" (Viridian, 2021)[17].

Profitability of company

The company Viridian Logic was founded in 2016, and had developed and made market-ready their modelling system to reach small-scale commercialization (Solar Impulse Foundation, 2021). While this is not the fast-pace that some technological new enterprises grow, it is still quite impressive given that their sector, NBs, is still a (growing) niche in the market.

1.2.3. Human Impact

First and foremost, the solution delivers "real benefits to a great many stakeholders" (IMEA Sustainability Awards, 2020) The stakeholders that can benefit through this solution include but are not restricted to policymakers, municipalities, local communities, and agricultural and other land-based actors (IMEA Sustainability Awards, 2020). This is achieved through multiple ways of working together:

First, regarding flexibility and inclusivity of the local socio-economic environment - HydroloGIS scores very high. HydroloGIS is able to incl. not only a myriad of local constraints and wishes but also recreation into its modelling approach. On a similar note, its "outputs are perfect for participatory design, so reduce consultation times and objections by up to 2 years" (Solar Impulse Foundation, 2021).

Secondly, concerning environmental inclusivity, it is able to integrate standard ecosystem service modelling. This includes but is not limited to factors like biodiversity, carbon emissions, crop farming and pollination (Solar Impulse Foundation, 2021; Viridian, 2021). In comparison to hard-engineered solutions, NBs identified by modelling systems like Viridian´s can save up to 95% of carbon emissions while achieving similar or even the same level of protection (Solar Impulse Foundation, 2021).

Thirdly, the data employed by HydroloGIS is open source or client data, making it highly affordable and customizable at the same time (Solar Impulse Foundation, 2021; Viridian, 2021). The efficient and effective use of this data makes it an affordable yet fast modelling system to identify the best NBs. This then accelerates the potential it has to be replicable for many sectors and actors (Solar Impulse Foundation, 2021; Viridian, 2021). This leads to a very high human impact achievable if adopted by clients.

1.3 Challenges & Solutions to Scaling

While Viridian Logic has overcome many challenges, from developing, testing and making market-ready its unique modelling solutions, there still lay many challenges ahead.

As of last year, Viridian Logic achieved small-scale commercialization. It has identified over 3000sqkm of natural interventions to solve local problems by modelling the most efficient and effective NBs (Solar Impulse Foundation, 2021).

However, at the same time, the company is still looking for funding, new clients and credibility. Without investment and buyers, the market impact might stay marginal. While the researchers found no news on large-scale public procurement or public funding, Viridian

[16] Please consult the following link for more detailed information: https://solarimpulse.com/solutions-explorer/hydrologis

[17] For detailed information about selection of solutions like Viridian´s, please consult the following Link of the IEMA Sustainability Award 2020: https://www.iema.net/articles/virtual-awards-real-success

Please also find an informative blog post of one individual contributing member of IEMA: https://www.iema.net/resources/blog/2020/10/28/viridian-logic-iema-sustainability-impact-award-winner-for-new-product-service-or-technology achieved success in collaborating with other companies in the private sector. It teamed up with the Climate Innovators Network by Kite Insights & Leading edge Only (LEO) (Solar Impulse Foundation, 2021) and formed a partnership with Ambiental Risk Analytics, a company of Royal HaskoningDHV (Royal HaskoningDHV, 2020).

Viridian Logic thus made use of networking and collaboration in the private sector to scale up its solution. Current news searchers, presentations to NAIAD in July 2021 and further advertising on Royal Haskoning DHV point to promising successes in scaling up the solution (Ambiental Risk Analysis, 2020; Royal HaskoningDHV, 2020; Stormwater, 2021).

Fruitful collaboration and increased visibility could lead to immense scaling since the technology itself is sophisticated enough to work at a "high 5m resolution from farm scales up to entire countries" (Solar Impulse Foundation, 2021). Indeed, experts from the Solar Impulse Foundation (2021) concluded that "Intelligent use of natural solutions crowds-in funding for nature, potentially unlocking $billions worldwide".

1.4. Feedback Loops

Viridian´s technological model allows stakeholders to plan the implementation and maintenance of NBs in such a way that it can prevent floods from occurring in certain catchment areas by stopping it beforehand. For example, through the construction of Woodland planting or the creation of meadows (Viridian Logic, 2021). It is evident that the effective implementation of such NBs will also mitigate the impact of flood disasters if they are not able to stop them. NBs do so in a non-intrusive and environmentally friendly way. Viridian´s solution furthermore makes sure that mitigation is effective since it reduces improper implementation. Finally, since NBs are themselves regenerative and implemented sustainably in the local ecosystem, recovering from floods is quicker and more effective, which in turn reinforces the feedback loop from Recovery to Prevention.

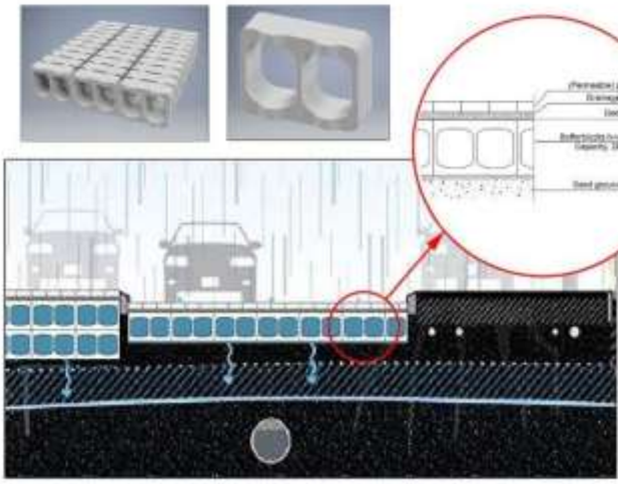
Bufferblock

Engineering-technological solution

Development of stormwater catchment blocks installed beneath the road in urban areas to store & redirect water

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description



• Given increase in percipitation & urbanisation; efficient and effective solutions are needed to deal with floods caused by stormwater in urban areas

• Conventional catchment systems are very expensive or cannot carry high traffic load

• Bufferblock fills this gap: It used high-tech engineering to create blocks that store water and still carry highy traffic

Innovation

• Bufferblocks combine maximum space for water with high stability

• Awarded the EU Business news Best Rainwater Drainage Solution 2021

• Solution is easy and efficient to implement, scale and maintain

Profitability

• Solution is more cost-effective in installation

• Maintenance is similarly cost-effective; Bufferblock can be inspected and cleaned with standard sewer equipment

• Currently at small-scale commercialization

Human Impact

• Optimally alleviates impact of floods, especially from stormwater for urban areas, hence has the potential to create immense value for more and more citizens living in cities.

• Installation is relatively easy and time efficient

Challenges, Solutions & Scaling

• Integrated feedback from clients successfully to accelerate their impact

• Company made great progress in designing, developing, testing and commercialising their products

• Two-year long testing and data gathering phase was completed in The Green Villagevisibility

• "Due to climate change we see great opportunities and an increasing need for water storage systems"

2. Mitigation

2.1 Engineering solution

2.1.1. Relevance & Context

Flash floods caused by rapid and excessive rainfall are among the three most common types of floods. Extreme precipitation due to climate change is expected to increase the frequency and intensity of flash floods (WHO, 2019; (United States Environmental Protection Agency, 2021). Drowning from floods accounts for 75% of deaths (WHO, 2019). In the US, vehicle-related deaths account for the majority of deaths during many floods, Over half of the fatalities from flooding and flash flooding from 2011 to 2020 has occurred in vehicles. Furthermore, vehicle-related deaths reached a 5-year high last year (National Weather Service, 2022; Pulver, 2022). However, such causes are in need of being confirmed on a global scale. What is nevertheless highly apparent is the unstopped and still accelerating increase in urbanisation worldwide (Ritchie & Roser, 2018). While the inclusion of NBs should be indispensable in building water-sensitive Delta cities, many cities are built out of concrete or need roads for transportation. However, roads have impermeable surfaces that can accelerate the impact of floods.

Hence, efficient and effective solutions are needed to deal especially with floods caused by stormwater in cities. The researchers searched in the Climate Innovation Window of BRIGAID (see 6. Methodology), EU databases and on the StartUs insights website to find the most innovative and impactful solution addressing this challenge. Among the most promising were

- Flood Con[18]
- AquiPor[19]
- Polder Roof[20]
- Bufferblock

After careful evaluation, Bufferblock was selected. The other solutions, while innovative and effective were either tackling side problems to flooding, like water pollution (Flood Con) or not creating as much impact as would be needed for municipalities to create also large scale flood mitigation (Polde Roof). Finally, and this holds true especially for AquiPor, but also for the other companies, they can be seen as a complement to Bufferblock´s solution.

2.1.2 Difference to other technologies

There are already a myriad of stormwater catching systems available on the market. Clinkers or levelling paving only creates marginal impact and often leads to pollution[21]. Another solution are infiltration crates. However, they are expensive to set up since they have to be laid deep in the ground[22]. Especially for cities with high groundwater levels this solution is inefficient since the crates there are very quick to be flooded. Finally, plastic crates are efficient and easier to implement, however, they lack in being able to hold heavy traffic loads[23]. Therefore, Bufferblock is one of the best solutions that can handle both large amounts of water, while being able to hold heavy traffic (Deltacommissaris & Bufferblock, 2020). According to an interview with director Hill Dorian Hill: "In contrast to plastic crates, Bufferblocks can handle large amounts of water with a high load-bearing capacity directly below street level. The blocks can also be used as lightweight filler material. In areas sensitive to settlement, the Bufferblocks also make it possible to elevate an area and store large volumes of water. In addition, the blocks can be easily cleaned just like the regular sewer system." (Smits, 2020).

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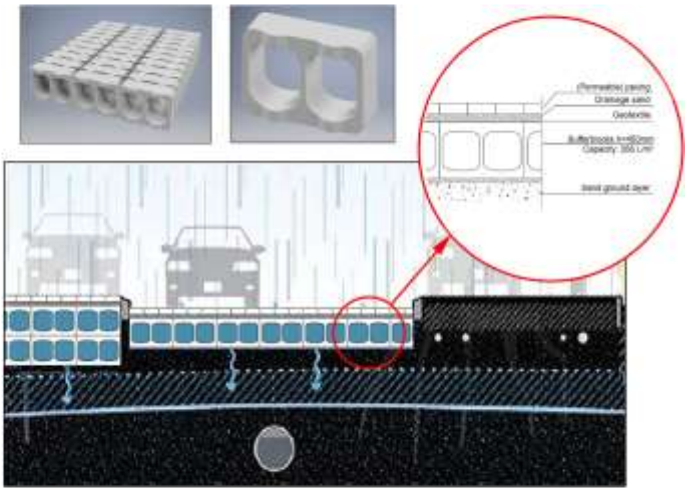
[18] https://flood-con.com/
[19] https://aquipor.com/
[20] https://dakdokters.nl/en/polder-roofs/

[21] For a more extensive analysis of benefits and drawbacks of these solutions, see: https://www.urbangreenbluegrids.com/measures/porous-paving-materials/
[22] For a more extensive analysis of benefits and drawbacks of these solutions, see: https://www.urbangreenbluegrids.com/measures/infiltration-boxes-and-infiltration-drainswells/
[23] For a more extensive analysis of benefits and drawbacks of these solutions, see: https://www.drainagesuperstore.co.uk/help-and-advice/product-guides/underground-drainage/storm-water-storage-crates/

2.1.3. Working of technology

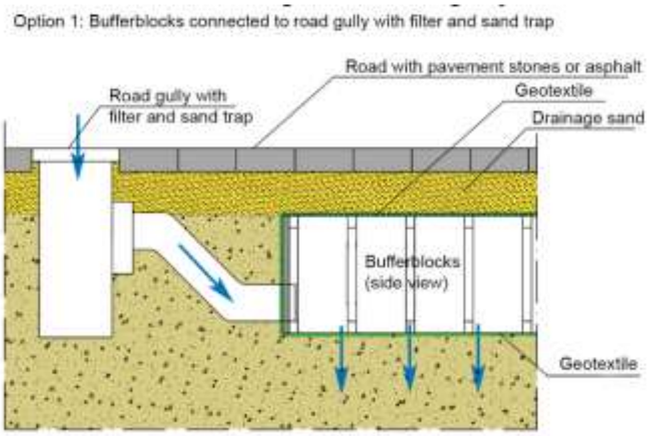
The Bufferblock solution is fundamentally a “high-tech engineering modelling to create a block that stores water and still carries high traffic load” (Bufferblock, 2020 {Nieuwe Waterberging- en Infiltratiesysteem [EN] New Water Storage and Infiltration System})

During heavy stormwater, Bufferblock allows water to infiltrate into the respective subsurface (Deltacommissaris & Bufferblock, 2020). Most often, below the subsurface refers to below street level. Figure x below shows well how the solution works.

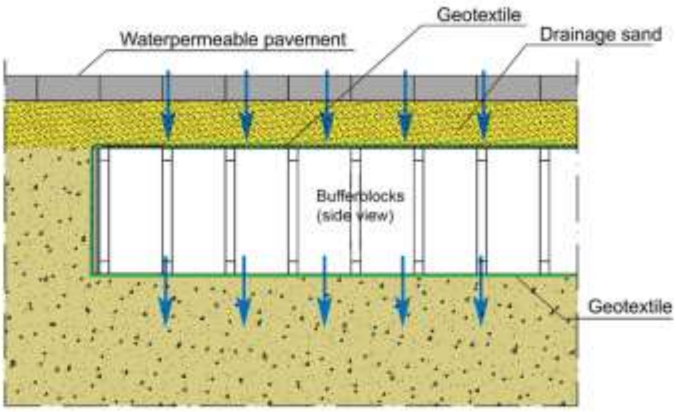


[***Figure 3***: *Visualisation of working of technology Bufferblock (Deltacommissaris & Bufferblock, 2020)*]

The rainwater enters through street gullies - see Figure 4 or through permeable road pavement - see Figure 5 (see useful compliments in section 2.1.2. above). The water is stored in the Bufferblocks temporarily. The storage capacity of Bufferblocks range from 266 to 532 litres per square metre[24]. The rainwater can then infiltrate farther into the ground or can be drained away (Deltacommissaris & Bufferblock, 2020). Concerning the mitigation of flood impact, a specialist at the world-premiere installation of Bufferblocks explains; “The big advantage of infiltration is of course, that the water no longer has to pass through pumping stations. When the pumping stations are relieved of stormwater loads, it will of course be better for all parties [own translation].” (Bufferblock, 2020 {Nieuwe Waterberging- en Infiltratiesysteem [EN] New Water Storage and Infiltration System})



[***Figure 4***: *Bufferblocks: Water enters through road gully given impermeable surface (Deltacommissaris & Bufferblock, 2020)*]



[***Figure 4***: *Bufferblocks: Water enters through waterpermeable pavement (Deltacommissaris & Bufferblock, 2020)*]

2.2. Evaluation

2.2.1. Innovation

While conventional systems had to compromise on strength or storage, Bufferblocks combine maximum space for water with high stability. They can be effective in mitigating floods by having large storage capacity while being useful for any urban area, even parking lots or highways for trucks. They were awarded the *EU Business news Best Rainwater Drainage Solution 2021* (EU Business news, 2022) and made the top-five in emerging stormwater management startups worldwide of the renomated start-up evaluator *StartUs insights* (StartUs Insights, 2020).

While it scores excellently on being an efficient and effective Stormwater solution, it has other benefits as well. Bufferblocks can be created out of environmental friendly material and are long-lasting. Hence, the solution

[24] See this link for more technical specifications, including size, weight and percentage of open space: https://www.bufferblock.nl/en/downloads-2/#technical

is sustainable as well. Moreover, the solution is easy and efficient to implement, scale and maintain. Finally, it is able to tackle the usually challenging problem of cities with high levels of groundwater since they require low installation depth. (Deltacommissaris & Bufferblock, 2020; Bufferblock, 2020 {Nieuwe Waterberging- en Infiltratiesysteem [EN] New Water Storage and Infiltration System})

2.2.2. Profitability

ROI for customers

As mentioned, Bufferblocks combine high water storage with stability to achieve the optimum effectiveness in mitigating floods while carrying high weights. This lays a solid foundation to guarantee a high return on this affordable investment for clients. The effectiveness and efficiency of the solution ranges from their fundamental design, to relatively simple installation to easy maintenance.

In comparison to infiltration crates, the high strength of Bufferblock means a thinner top layer is required. This in turn reduces the installation depth while guaranteeing high buffering capacities. Hence, the solution is more cost-effective in installation. The simplicity of installing the blocks an be observed by a snapshot of loal construction in Figure 6 (Deltacommissaris & Bufferblock, 2020).

[***Figure 6***:*Installation of Bufferblock on site (Deltacommissaris & Bufferblock, 2020)*]

Maintenance is similarly cost-effective. While other solutions require specialised maintenance, Bufferblock can be inspected and cleaned with standard sewer equipment (Deltacommissaris & Bufferblock, 2020).

Finally, the Bufferblock solution has myriad benefits beyond mitigating the effect of floods. It is able to store or redirect water where necessary. It also makes sure that soil is infiltrated at a slower, more absorbable pace. This means it can ensure more effective soil infiltration. Hence, it is able to alleviate heat stress and droughts (Bufferblock, 2020 {Nieuwe Waterberging- en Infiltratiesysteem [EN] New Water Storage and Infiltration System})

Profitability of company

The company was founded in 2018 and has its main office in Rotterdam. Their solution is implemented on a national scale at the moment (Deltacommissaris & Bufferblock, 2020; Crunchbase Inc., 2021).

With several successful pilots completed, Bufferblock is at the completion of prototype testing in the real world and simultaneously acts in initial market commercialization (Deltacommissaris & Bufferblock, 2020; Bufferblock, 2022).

Since its founding Bufferblock has raised around €100.000,- to develop and scale its innovative products (Dealflow.eu, 2021). In the year of 2019, under the European Innovation Council and SMEs Executive Agency, the company raised a budget of €71.429,- with an EU contribution of €50.000,- (Crunchbase Inc., 2021; European Commission & CORDIS EU Research Results, 2020). Another investor is Navus Ventures, a Dutch venture capital firm investing in, among others, sustainable storage sectors in the Netherlands and neighbouring countries (PitchBook, n.d.). Finally, in January 2020 another funding round of around €50.000,- was realised with EIT Climate-KIC, one of Europe's largest cleantech accelerators (Dealflow.eu, 2021).

2.2.3. Human Impact

The Bufferblock solution optimally alleviates the impact of floods, especially from stormwater for urban areas, hence has the potential to create immense value for more and more citizens living in cities. Furthermore, installation of the Bufferblocks is relatively easy and time efficient, making it attractive to small and large municipalities, as well as minor to major other public authorities.

Furthermore, the solution is flexible in design; Director Dorian Hill explains in an interview: “The system is based on separate elements that can easily be arranged in all kinds of configurations. Together with engineering offices and municipalities we search for the best and most efficient way to store the excess rainwater, allowing it to infiltrate or drain into surface water, sewage or water purification facilities where necessary” (Smits, 2020).

Additionally, Bufferblock´s maintenance is neither cost nor knowledge-intensive. Dorian Hill advocates : “It also appeals to municipalities that Bufferblocks use the same method of maintenance and inspection as is used for sewer systems since they already have a lot of experience with that” (Smits, 2020).

Beyond cost-effectiveness and flexibility in design, implementation and maintenance, Bufferblock´s solution has two other main benefits. First, water that is collected in Bufferblock goes back to e.g. provide for droughts or water plants. This was already realised successfully in the project Diergaarde Blijdorp [EN] Rotterdam Zoo (Bufferblock, 2020). In general, a main benefit over infiltration crates is that Bufferblocks guarantee a slow infiltrating of water into the soil (Bufferblock, 2020 {Nieuwe Waterberging- en Infiltratiesysteem [EN] New Water Storage and Infiltration System}). Secondl, the blocks are environmental friendly and long-lasting, making it a sustainable investment for clients: "the Bufferblocks can be made from recycled concrete and have a long lifespan" (Deltacommissaris & Bufferblock, 2020).

2.3. Challenges, Expectations & Solutions

As already deductible from their several successful funding rounds since their founding only four years ago, the company made great progress in designing, developing, testing and commercialising their products. Moreover, they integrated feedback from clients successfully to accelerate their impact. During the execution of Bufferblock projects, clients deemed it useful to be able to connect the Blocks to existing sewers. Adopting this wish into their design, the Bufferblocks can now be used as an infiltration/drainage transport sewer pipe as well (Bufferblock, 2022).

At the end of last year, a two-year long testing and data gathering phase was completed in The Green Village. During this phase, test on strenght, water storage volume and infiltration rate were conducted in the Waterstraat of the Delfland Water Board, VP Delta and Green Village on the TU Delft site. The Green Village is an organisation uniting stakeholders to connect innovation with entrepreneurship, located at the physical location of Delft Campus in South Holland[25]. (Bufferblock, 2022; Smits, 2020).

Following this successful prototype testing, the Bufferblock solution has been optimised and made market ready for mass-production. The solution has now been applied in five projects: namly in Capelle aan de Ijssel in South Holland, Diergaarde Blijdorp/Rotterdam Zoo, Zevenkamp in Rotterdam, Dordrecht and Zwijndrecht in South Holland as well.

The project in Capelle aan den IJssel, near Rotterdam, has reaped the substantial benefits of the solution already: The Bufferblocks have been used in the residential area to prevent urban flooding and minimise soil settlements (Climate Innovation Window & BRIGAID, 2021). This project was the world-premier of the Bufferblock solution. According to key representative of the solution on the site, many more municipalities were interested in the solution (Bufferblock, 2020, New Water Storage and Infiltration System).

However, there are still challenges to phase, especially since the solution is not yet well-known on a trans-national or global scale. Director Dorian Hill explains in an interview: "It's [Bufferblocks] another new system, so you have to explain it well"(Smits, 2020). This indicates that, as with many new innovations, credibility and visibility still remains a challenge to achieve maximum scale and impact.

Nevertheless, given recent successes, Bufferblock is holding advanced discussions with several municipalities in the Netherlands. Interests have also been expressed overseas, for example in the United Kingdom (Smits, 2020).

Apart from national and possible trans-border expansion, knowledge transfer is becoming a real possibility for Bufferblock. According to a Bufferblock specialist at the construction of the world-premier in Capelle aan den IJssel; "We [Bufferblock team] are the forerunner. We will provide data to others [own translation] " Specifically, he adds that: "...with online sensors the blocks will be monitored to check the water levels inside the blocks and the soil settlements. This data will be shared with other municipalities who want to know more about the effects of the Bufferblocks in preventing urban floodings and minimising soil settlements" (Bufferblock, 2020, New Water Storage and Infiltration System). This could potentially be shared on a global scale since Bufferblocks long-term goal is to make its solution available beyond Dutch cities. This means that many interested cities on a global scale, facing the same challenges under climate change, could benefit from this innovative solution (Bufferblock, 2020 New Water Storage and Infiltration System). Answering the question: Where will Bufferblock be in five years´ time [Interview was 2020, hence from standpoint 2020 in 3 years time]; Director Dorian Hill elucidates: "We hope to be active not just in the Netherlands, but also in Germany, Belgium and

[25] For more information on Green Village; please consult the following Link: https://www.linkedin.com/company/thegreenvillage/)

FloodMap - Satellite Data

Technological Modelling solution

Highly accurate flood forecasting, real-time flood monitoring and water levels available right after flood

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description

• FloodMapp provides solutions in three Disaster Management stages: Preparedness through early warning, Response through Live Modelling and Recovery through instant water level data availability post-flood

• Shifted from the conventional physics-based approach used in hydrology to move toward a data-driven approach

Innovation

• FloodMapp has developed a world-first flood modelling technology to predict flooding at a granular, street-level in real-time

• FloodMapp is collecting real-time ground observation data to validate models

Profitability

• Initial funding round of $1.3 in 2019

• Further seed funding leading investor Union Square Ventures (USV), at the beginning of the year should allow further development and scaling

Human Impact

• Real mission with a bottom-up approach

• More intelligence on ground level - people make targeted decisions, take their valuable belongings, etc.

• Meaningful collaborations and successful projects

Challenges, Solutions & Scaling

• Spending a majority of time on building a first prototype (an app at the time, not a highly compatible software as is employed now) was not productive and efficient in the long-time

• Product now highly successful & integrated with Google's Waze

• Collaboration with other private firms in insurance market

• Business received inquiries from Brazil, the Philippines, India, Europe and the UK over the past few months

3. Preparedness

<u>3.1. Socio-technological solution</u>

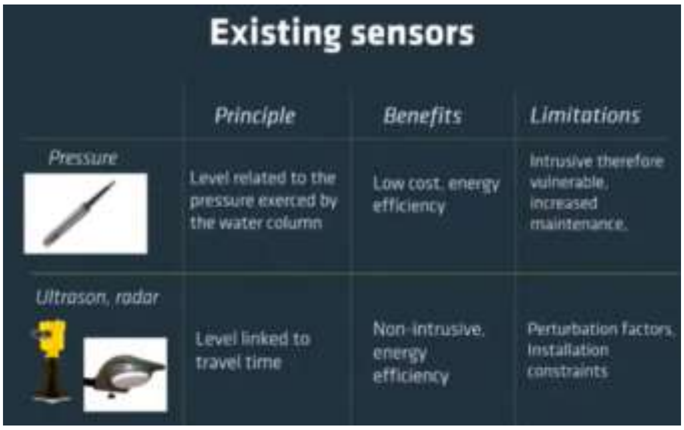
<u>3.1.1. Review of technologies and selection of Best-Practice/Relevance & Context</u>

The Preparedness stage is one of the most recognized stages among stakeholders to react to flood disasters. Beyond building dams and the like, officials have laid a large focus on being prepared for disasters through effective early warning systems. While implementation of said systems still faces many challenges, the market for early warning (emerging/new) technologies, at least in the Western World, is considered by many quite saturated (Emergen Research, 2022; PVT01, PVT02, PUB03).

However, creative Entrepreneurs continue to find unconventional ways to combine cost-effective sensors with machine learning algorithms and artificial intelligence to improve accuracy in monitoring river levels or complementing Meteorological data for pluvial and fluvial flood forecasting. Two interesting start-up examples of such creative technological interventions are the French company (1)Tenevia and the (2) Dutch company sustainably[27].

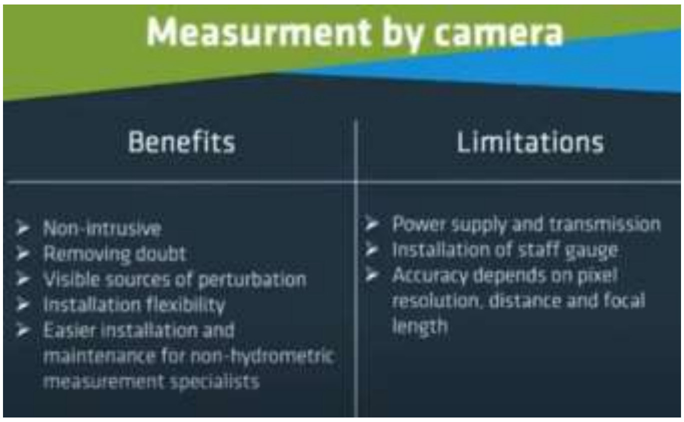
<u>(1) Tenevia</u>

Tenevia (n.d.) developed camera sensors placed above standing or moving waters (e.g. reservoirs, turbulent river flows, etc.) to measure, monitor and forecast the evolution of rivers and hence floods. The so-called *CamLevel* measures the water levels of rivers differently from conventional sensors. Tenevia (2020) provide the following overview of existing sensors in an online webinar:



[***Figure 7***: *Summary of benefits and drawbacks of conventional sensors (Tenevia, 2020)*]

The CamLevel has several benefits, extending the ones of conventional sensors. When combined with conventional sensors, it can greatly improve the measurement accuracy of fluvial flooding. Tenevia (2020) give the following overview of benefits and limitations in their online webinar:



[***Figure 8***: *Summary of benefits and drawbacks of conventional sensors (Tenevia, 2020)*]

The main advantage is that the camera is not submerged and is hence protected from floating debris (Tenevia, 2020).

The measurement of the water level is carried out through automated detection of the waterline through image sequencing. So the smart system employing image recognition software and machine learning compares one image of the water line to another and determines the difference. Connected with a staff gauge, this allows for easy and intuitive visualisation, as seen in Figure 9.

[27] For an in-depth review and assessment of Flood Early Warning Systems for Flash Floods, please consult the following journal article (Henao Salgado & Zambrano Nájera, 2022)

For an in-depth analysis of Range-dependent thresholds for global flood early warning please consult the following journal article (Alfieri et al., 2019)

[***Figure 9***: *Example of technological visualisation (Tenevia, 2020)*]

The Entrepreneurs behind the solution founded the company in 2012. Arnaud Brun and Georges-Marie Saulnier based their sensors and software on advanced scientific research. The company originated from a European Alp-Water-Scarce project; through innovative technology incubators, the IMAGINE project that the two researchers launched became a reality in the form of the simplified joint-stock company TENEVIA.

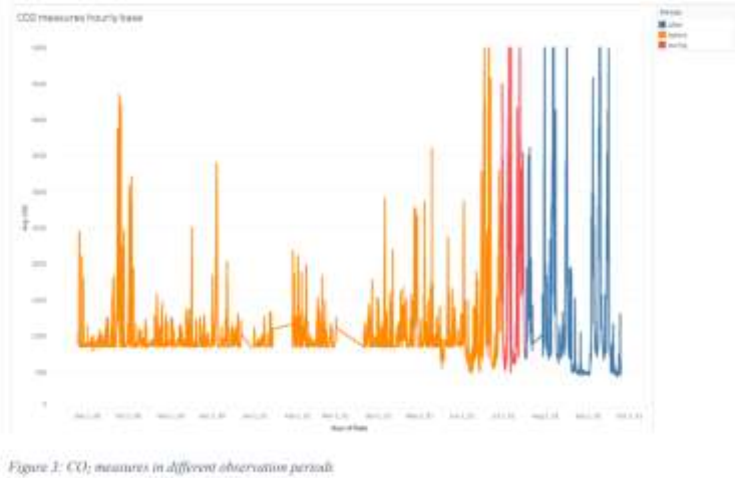
This solution, while not revolutionising the way in which flooding is forecasted, is still highly innovative. It was awarded the Jeune Entreprise Universitaire (New University Company) and Jeune Entreprise Innovante (New Innovative Company) labels in 2013. Two years later, in 2015, it got awarded the BPI France's Enterprise Innovante (Innovative Company) label (Geneva, n.d.). This indicates an interconnectedness from innovation to more growth to more investment into innovation is evident.

Concerning scaling, the company has recently been sold to a group (Personal communication, 03 June 2022). It can hence be interpreted to be successful in creating more human impact. The main clientele of the company is public actors: municipalities, cities, governmental departments or other local authorities and waterway management associations (Geneva, n.d.).

Finally, even though the company was not selected as a best practice, its technology made considerable progress in real-life modelling of fluvial flooding. Their monitoring devices provide real-time information about water levels during flood events. The technology hence acted in the preparedness and response stage.

<u>(2) Sustainably.io</u>

A second unconventional, creative, but promising solution to predicting pluvial flooding is being developed in Maastricht, the Netherlands, by Researcher and Entrepreneur Burak Can and his Master's student team as well as interns. The recently founded start-up sustainably.io focused on air quality measuring devices. When the social start-up installed and observed air quality levels in households in a former mining city, they observed something particularly interesting. A stark difference in CO2 levels in the periods before-, during and after flooding in the former mining city was observed - see Figure 10.



[***Figure 10***: *CO2 measurement over different time periods; before flooding (orange), during flooding (red) and after flooding (blue)*]

These preliminary findings could open up a prediction of flooding using the measurement devices of sustainably.io. This is an innovative example of an emerging social enterprise that adopts unconventional ways of using, here, machine learning and CO2 leakage to predict flooding in challenging areas.

While research groups and municipalities do show interest in these devices, the start-up is, to date, in the earliest maturity stage: Prototype testing 1:1 in the lab and in the real world. Additionally, it has to be pointed out that this company is a good example of sustainability and inclusivity throughout the production process. The production is carried out in Maastricht itself in an organisation employing people with Down syndrome, people with disabilities or refugees. The material of the sensors is biodegradable. Finally, the underlying mission is a social one driving all involved stakeholders. While there is the possibility of scaling, the way in which scaling might be realised must also be sustainable and inclusive, according to involved personnel in sustainably.io. This could potentially reduce the pace at which the company can scale and create more revenue. However, creating revenue is not the objective of this start-up (PVT 03, Sustainably.io, 2022; JulyViefhues, J.-P., 2022)[28].

These two start-ups exemplify well how creative and unconventional solutions open up new ways of increasing resilience through early warning in the Preparedness stage.

[28] To learn more about the flood prototype in development at sustasinably.io, please get in contact with the organisation through its website: http://sustainably.io/

Nevertheless, they are complementary rather than market revolutionising solutions. As explained in the first part of this report in the market analysis of Disaster Management, one of the major technological advancements currently transforming the market is satellite technology. Emergen Research (2022) explains that technological advancements in satellite technology, together with Artificial intelligence has greatly improved weather predictions and damage maintenance. The market analysis furthermore explained that satellite technology allows greater preparedness and resource placement as well as recovery through better damage assessment and understanding of where restoration is required. Emergen Research (2022) points to AiDash, a leading provider of satellite and AI-powered solutions, who developed and recently launched a disaster management system based on satellite data and analysis. While the system focuses on storms and wildfires, great advancements have been made especially in the flood sector.

Through a search in start-up evaluator platforms and webpages, a start-up focused on satellite technology stands out: ICEYE. The company made great advancements in the field of collecting, analysing and providing satellite data related to natural disasters. ICEYE was able to scale and raise funding rapidly over the last 7 years. Over the period of 2014/15 (transition from Stanford University Technology Venture program to a registered company) to the beginning of 2022, it raised $261mio in funding. It had also expanded its operations from Finland to Poland, the UK, the US and Spain. The readiness of the satellites for a specific location is immense. ICEYE has one of the largest SAR satellite constellations and can therefore image anywhere in the world within hours, according to CEO Modrezwiski (ICEYE, 2020; Sheetz, 2018). Fundraising of this scale was referred to as ”a standard Silicon Valley round” by Sheetz (2018). While these factors can certainly generate a lot of value for stakeholders, particularly from the business and larger governmental sector, ICEYE remains a profit-oriented company. At the stand of 2018, ICEYE acquired “data globally and constantly but its data are not freely accessible” (Cian et al., 2018). Furthermore, many stakeholders from the private engineering and governmental sector are already using their own sources for satellite data or open-source data. While higher accuracy in evaluating a large area is recognised as helpful, especially for governments or organisations with limited capacities and resources, this is considered a future complementary solution rather than an solution catering to an acute need to increase resilience. Furthermore, satellite technology still has many limits for flood management (Mapscaping, 2022; PUB03; PAP02)

ICEYE also scores lower on the social aspect crucial for the most essential criteria of this review: Human Impact.

Hence, a second review of non-satellite companies was conducted. Many companies did however use satellite technology as a complementary check for their modelling systems.

Among start-ups, FloodMapp stands out as it provides highly accurate flood forecasting, real-time modelling and a comprehensive strategy, including sustainable recovery. A further major point of how it stood out among others was that it is not a stand-alone solution but continuously looks for partners to improve its modelling solutions with the core value of increasing resilience of the most vulnerable. FloodMapp is one of the 5 Top Emerging Stormwater Management according to StartUs insights.

3.1.3. Working of technology & Differentiation to competitors

[***Figure 11***: *FloodMapp provides solutions in all three Disaster Management stages: Preparedness through early warning, Response through Live Modelling and Recovery through instant water level data availability post-flood (FloodMapp, 2020)*]

Figure 11 depicts well how comprehensive FloodMapps modelling services are. Especially a near-real-lifetime model (NowCast) is something that was rarely available on the market when the company was founded in 2015. At that time, forecasting and modelling, in general, focused on meteorology and hydrology (Dorgan, 2022c)

These modelling methods, as already discussed in the Viridian NBs case study, are often still quite static and rigid, failing to fully seize the potential that new big data, machine learning and deep learning have to offer (Crunchbase, 2021). Furthermore, these modelling and forecasting systems were mainly developed and used for and by government officials or municipalities. Rarely was a model accessible or understandable for the average citizen, who is often the most vulnerable (Crichton, 2021; PUB01; PAP01).

The founders of FloodMapp, Juliette Murphy (now CEO) and Ryan Prosser (now CTO), however, wanted to develop models not only for decision-makers on a municipality or government level but also for the average citizen. They, therefore, wanted to move away from the conventional physics-based approach used in hydrology to move toward a data-driven approach. This allows seizing the benefits of more broadly available techniques in computer sciences to make previously highly complex solutions easier to deal with for modelling and forecasting. More specifically, the time-intensive calculations of second-order differential equations are needed for high-resolution modelling (Crichton, 2021; FloodMapp, n.d.).

Instead of using rigid and computational complex hydrological modelling techniques, FloodMapp used real-life data. Juliette Murphy explains in an interview: "We have really sort of broken the speed barrier." (Crichton, 2022). The work that went into this transformation led to the creation of DASH, the company's real-time flood Model (NowCast) (Crichton, 2022). DASH was created by FloodMapp's multidisciplinary team, bringing professionals from the industry, academics and data scientists together. DASH stands for Dynamic Automated Scaleable Hydroinformatics. The purpose-built modelling system provides information in real-time from forecasted rainfall and river heights. It's highly precise from the street level to national views. It reaps the benefits of new cutting-edge technology and scientific accomplishments with traditional engineering approaches (FloodMapp, n.d.)

As evident in the above graphic (Figure 11), FloodMapp provides its services before (ForeCast), during (NowCast) and right after (PostCast) a flooding event happens. This means it acts at three key stages of the Disaster Management cycle: Preparedness, Response, and Recovery (FloodMapp, n.d.).

In the Prevention stage, conventional forecasts, while being quite advanced, are still mainly provided as flood height. This does not deliver an understanding of where exactly and by how much the flood impacts a given terrain (FloodMapp, n.d.). However, there has been an increasing call for having this information in a format that is more helpful to community members on the ground level. With many generic flood warnings, certain tiredness from the social sector is expected in many cases (PUB01; PUB03). Here, FloodMapp´s DASH can provide specific flood impact information at the property level (see Figure 12). DASH can deliver Flood information at the street level since it runs on an up to the 1-metre grid, enabling a 200 times finer picture than conventional models (FloodMapp, n.d.)

[***Figure 12***: *FloodMapp´s DASH Forecasting model (FloodMapp, n.d.*]

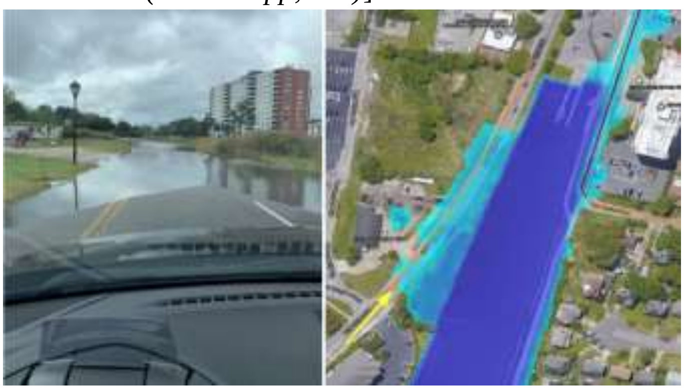
The model ingests real-time river height and rainfall data to deliver highly accurate forecasts. According to FloodMapp (n.d.), their model proved 90-96% accurate in predicting flooded areas (see Figure 13). Their Flood impact maps are available up to seven days ahead of the actual flood occurrence. [29]

[29] To know more about FloodMapp ForeCast, please consult the following link with benefits and drawbacks as well as case-studies: https://www.floodmapp.com/forecast

[***Figure 13****: FloodMapp Forecast (green) compared to real flood impact (FloodMapp, n.d.)*]

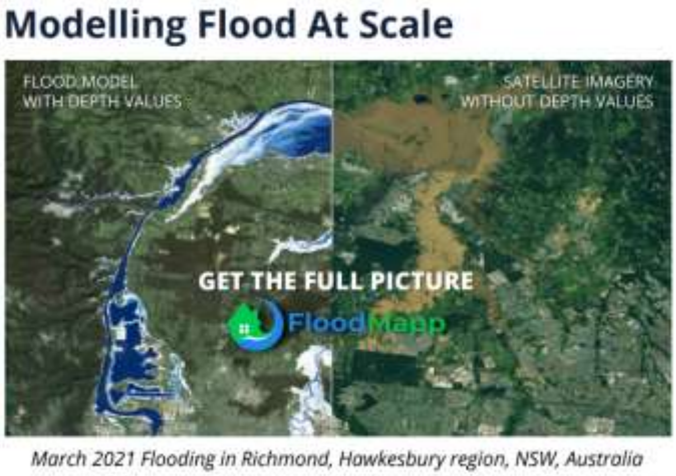
For their NowCast model, FloodMapp (n.d.) relies on real-time rainfall data and river height information. It can deliver dynamic flood information on live mapping feeds as the flood is happening (see Figures 14 and 15). Traditional models and satellite imagery is not able to provide the same accuracy and real-time information. This lack of timely information can lead to lacking situational awareness, in turn endangering lives (FloodMapp, n.d.)[30].

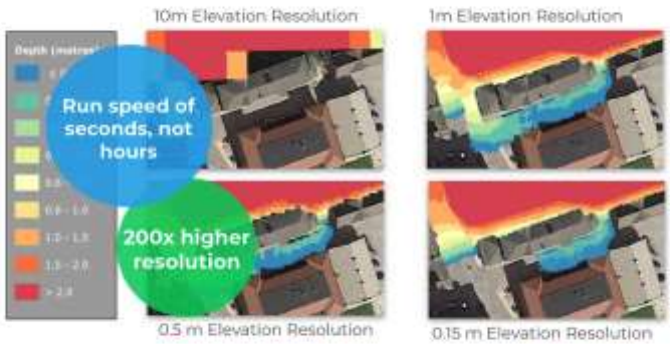
[***Figure 14****: Example of NowCast modelling visualisation at real time (FloodMapp, n.d.)*]



[***Figure 15****: Example 2 of NowCast modelling visualisation at real time (FloodMapp, n.d.)*]

Finally, in the recovery stage, many efforts of first responders and general resource coordination are still in need of optimization. FloodMapp´s Postcast model can help here as well. While physical flood surveys and inspections are timely and costly, detailed information about local flood extent and depth information can enhance understanding what is needed where. FloodMapp´s PostCast models can map the depth values in great detail at different timesteps. Furthermore, it can identify the number of assets impacted and estimate reconstruction costs (FloodMapp, n.d.)[31].





[***Figure 16 and 17****: Example for PostCast flood event package (FloodMapp, n.d.)*]

While these modelling approaches were already transformative for modelling and forecasting, FloodMapp´s modelly system interoperates with GIS. This is possible by offering a data layer which can be combined with other data streams. Furthermore, they continuously seek new partnerships and collaborations to make its models more accessible to broader populations (FloodMap, 2020; TechCrunch, 2022)

Most recently, at the beginning of this year, FloodMapp´s DASH is being integrated with the navigation app Waze through a pilot program in Norfolk, Virginia (Dorgan, 2022c). Google-owned Waze is a

[30] To learn more about how FloodMapp NowCast can improve the response to a disaster, please consult the following link: https://www.floodmapp.com/nowcast

[31] To know more about FloodMapp ForeCast, please consult the following link with benefits and drawbacks as well as case-studies: https://www.floodmapp.com/postcast

navigation app for private cars. It "collects this information and immediately analyzes it in order to provide other Wazers with the most optimal route to their destination, 24 hours a day" (Google Support, n.d.). Juliette Murphy, co-founder and CEO of FloodMapp, explains that "by mixing tidal, riverine and rainfall data, the company's forecasting technology allows drivers using Waze to receive pop-up icons and audio alerts, warning them about flooded streets along their route to help avoid property- and life-threatening hazards." (Dorgan, 2022c).

3.2. Evaluation

3.2.1. Innovation

In the above sections, it has already become clear how innovative and unique FloodMapp´s solution is from a technological perspective. In a recent funding round for FloodMapp, leading investor Union Square Ventures (USV) confirmed the innovativeness of the solution. Partner Nick Grossman states: "The world is facing a climate crisis, and we need the best and brightest thinkers, innovators and inventors from around the world to turn their collective talent to finding solutions" Dorgan (2022b). They are "thrilled to partner with FloodMapp, our very first adaptation-focused investment. FloodMapp has developed a world-first flood modelling technology to predict flooding at a granular, street-level in real-time" (Dorgan, 2022b). While this innovation is certainly remarkable, another important point for USV was the coordination and collaboration with other companies; "what excites us most about FloodMapp is the data network effect. By working with emergency managers and communities through partnerships like Waze, FloodMapp is collecting real-time ground observation data to continually validate and improve models" (Dorgan, 2022b).

3.2.2. Profitability & customers

FloodMapp works together with government bodies and critical infrastructure managers. However, given their primary goal to protect people at the property level and empower them through meaningful information, they also offer products to property owners. Finally, FloodMapp hopes to enhance its impact and profitability by collaborating with companies in the insurance market (Dorgan, 2022b).

FloodMapp is already available across large parts of Australia and covers 90 per cent of the continental USA. Its initial funding round of $1.3 in 2019 from Shark Tank's Steve Baxter's Transition Level Investments (now rebranded as TEN13), Allectus Capital, and Jelix Ventures led to rapid scaling (Crunchbase, 2022b; Dorgan, 2022c). At the start of this year, another important funding round was finalised. As mentioned above, it was led by New York-based venture capitalist Union Square Ventures (USV) (Dorgan, 2022b).

While funding is indispensable for any start-up, the managing team at FloodMapp looks out for investors that are driven by a somewhat social mission or at least agree with compromising on profit for resilience to some extent. In an interview concerning this most recent funding round, Juliette Murphy, CEO, was confident that "their [USV] investment thesis and the way that they worked really aligned with what we were trying to achieve," Murphy says.
(Dorgan, 2022b)

3.2.3. Human Impact

Synthesising various news articles and general online presence as well as the content published on FloodMapps's website, it becomes apparent that the people driving the start-up's success have a deeply rooted social mission at heart. Co-founder and CEO Juliette Murphy has experienced flooding, studied environmental engineering specialising in water resources and started her career in consulting. While she enjoyed solving complex problems for and with companies, she explains that by becoming an Entrepreneur, "you're getting to solve a problem that you care deeply about and really push the boundaries to bring something new to life." (Dorgan, 2022c) Together with experiencing the adversity of flood disasters herself, a real mission with a bottom-up approach was born: "It struck me, whilst government agencies are doing an incredible job, there was a real lack of hydraulic forecasting" (Dorgan, 2022c). Murphy saw the potential power and resilience that hydraulic modelling could give to people at the property level; she explained that with more intelligence on the ground level in terms of early warning of the infrastructure that will be affected by flooding: "people could have that knowledge to make targeted decisions and make moves to take their valuable belongings or save their lives in some cases" (Dorgan, 2022c).

The social mission and entrepreneurial spirit, as well as a small but motivated team, drove many meaningful collaborations and successful projects that have already increased the resilience of many vulnerable people against flood disasters in preparing better, responding more efficient and recovering with more easy and sustainability (Armstrong et al., 2022; Crunchbase, 2022a; Crunchbase, 2022b; Dorgan, 2022a; Facebook, FloodMapp, 2022; Murphy, 2022a; Murphy, 2022b; Facebook, FloodMapp).

In a recent interview, Juliette Murphy stated that FloodMapp is "now seeing the impact of our live tours updating every 15 minutes, pushing live flood hazards, based on our predictive modelling, to drivers on the road that can then avoid those hazards in real-time" Dorgan, 2022c). The co-founder is confident and motivated to keep going: "And our team has done that, and I think there's just nothing more rewarding, and it gives me goosebumps" (Dorgan, 2022a).

Lastly, FloodMapp also stands out in the way that they continue working with and for clients after a disaster: "As a team, we do technical debriefs following any major event, and as a people-first organisation, we also look at how our response affected the health and wellbeing of our team as well," She furthermore explains the benefits of this for the affected and vulnerable: "We make time for these kinds of debriefs because we know we are in reaction mode in the heat of an emergency, so it's important to take time afterwards to stop and reflect" (Dorgan, 2022a).

3.3. Challenges, Expectations & Solutions

When looking at FloodMapp's past successes, it is important to recognise that as a start-up, the company had faced many challenges that would have been approached differently now. Juliette Murphy explains in an interview that spending a majority of time on building a first prototype (an app at the time, not a highly compatible software as is employed now) was not productive and efficient in the long-time as it did not cater to the specific needs of the market. Time invested to pursue such a stand-alone app feature would have been better invested in developing the current Application Programming Interface (API) product (Dorgan, 2022c).

This product is now highly successful as it is being integrated with Google's Waze (see above). Further seed funding at the beginning of the year should allow further development and scaling. However, also here, the social mission is important for Juliette Murphy, CEO and co-founder. In an interview about the recent seed fundraising round, she explains: "We'll be scaling up our technical engineering team, as well as our go-to-market team here in Australia, but also in the US to expand that capability [...] So for us, this means that we're helping more emergency managers, more communities to improve safety and prevent damage from flooding that is getting more severe every day" (Dorgan, 2022b). This recent investment can be seen as a confirmation of the technologies value and the need for it on the market (Dorgan, 2022b; Emergen Research, 2022).

However, FloodMapp also expanded its impact through collaborations and expansion into the insurance market. Most recently, they have collaborated with Codification. Codification's Crunchworks software was able to integrate both technologies within just a few days (Day, 2020; Dorgan, 2022c). The joint force's approach can accelerate the pace of insurance response, meaning high-risk claims can be dealt with more efficiently and effectively. The contribution of FloodMapp's models is that they provide real-time automation of where claimants are located in relation to floods. Daniel Sandaver explains in an interview that "The speed in which you provide this data is important because it translates into faster triaging and assessment capabilities, prompt emergency responses from assessors and efficient resource allocation to the right claims" (Dorgan, 2022c).

While this collaboration could increase revenue rapidly by bringing in profitable big insurance companies, FloodMapp Juliette Murphy still focuses on the real effect for vulnerable people on the ground level, at the end-spectrum. In the same article about collaboration with Codification, she explains: "We know that with better situation intelligence before, during and after floods, there is a better chance that people, assets, and infrastructure can be better protected and more easily fixed" (Dorgan, 2022c). An important remark was also made by Daniel Sandaver, Codification co-founder and managing director, about general collaboration among businesses. He is confident that "if more technology providers can work together on powerful integrations, such as the partnership between Codification and FloodMapp, it would improve how the insurance industry is supported, equipping them with powerful tools and resources when they come up against a natural disaster" (Dorgan, 2022).

Region of Impact and global scaling

FloodMapp's technology is available across Australia and the continental USA. However, global scaling is a key goal for the start-up. Current news articles explain that "the business has started to receive inquiries from Brazil, the Philippines, India, Europe and the UK over the past few months" (Dorgan, 2022b). The challenge to fast scaling is technology al in nature. Juliette Murphy explains: "We wish we could scale it quickly, but it's not a file-sharing app that is inherently scalable" (Dorgan, 2022b). While capital intensive, when equipped with real data, the technology can be transferred, albeit slowly; as Murphy elucidates: "From day one, we are dealing with physical data here, we need information about the terrain, seeing the topography of the land, we need information about all the hardware installations for flood sensors and rainfall sensors, and that kind of thing, which does sometimes take time" (Dorgan, 2022b).

I-REACT - Multi-stage system

Socio-technological solution

Multiple-Source Data collection and distribution incorporating civil society for real-life response action

Best-practice description

- I-REACT is an early warning action system developed in a 3-year long project - now commercial
- Information from European monitoring systems Earth observations, Historical information, Weather forecasts
- Technologies developed: Mobile app, Social media analysis tool to account for real-time crowdsourced information, Drones for improving mapping, Wearables

(Aquobex Technologies, 2019)

Innovation

- Next-generation multi-hazard early warning system - ahead of marketplace at development stage (Member i-REACT).
- "Leveraging innovative cyber technologies & ICT systems, achieve effective preparedness empowering stakeholders" (EC)

Profitability

- According to a managing team member, prices are competitive
- Recent prices municipalities low prices for the professional app and wearables per user per month (€5,- & €10,-), higher prices for the Social media App per system per month (€5.750,-)

Human Impact

- Great progress in connecting data sources and stakeholders
- Currently in medium to large-scale commercialisation
- Focus has always been on the developing world and SIDS
- Replicable as software - to generate maximum impact

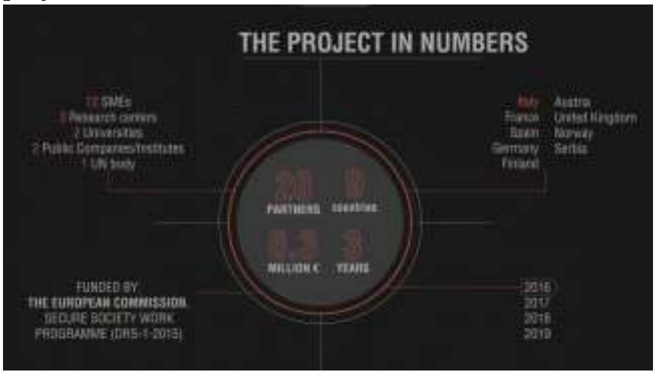
Challenges, Solutions & Scaling

- "Biggest obstacle was the exploitation of the produced output" - "The division of effort and reward should have been dealt with at beginning"
- Outdated software as University free software was used; "In a similar situation, we would examine the proposed architecture in more detail up front, with our colleagues [...] with considering what the future would look like at the end of the 3-year grant"
- Collaboration with other private firms to upgrade software in progress

4. Response

4.1.1. Relevance & Context

While some web-based emergency market companies offer holistic services, including multiple stakeholders and data services, there is still a large area for improvement in using cyber technologies to increase resilience comprehensively. A forerunner of such a multiple-stage system is i-REACT. I-REACT is an early warning action system developed in a 3-year long project.



[*Figure 18*: *i-REACT project in numbers (I-REACT, 2016)*]

The European Horizon 2020 funded project that brought together research and educational institutes, governments and UN bodies. At the end of the project, it was turned into a viable company, Aquobex Technologies(Aquobex Technologies, 2019; EC, 2019;). The following infographic from the European Commission summarises the project process, funding and output well.

[*Figure 19*: *Infographic i-REACT project, (EC, 2019)*]

The project lead was coordinated by Fondazione LINKS, an Italien based but internationally acting organisation fostering innovation[32].

The project's ultimate goal was to develop solutions for a disaster-resilient society through modern cyber technologies and multiple data source integration. It should empower stakeholders in key phases of the Disaster Management cycle (I-REACT, 2019] This goal was realised by deriving information from European monitoring systems, earth observations, historical information and weather forecasts, and social media crowdsource information. This was a highly innovative aspect at the time since crowdsourced information was not gathered in this systematic form previously.

Data was gathered and analysed through established and newly developed technologies; this includes a Mobile App, a Social media analysis tool to account for real-time crowdsourced information, Drones for improved mapping and Wearables for improved positioning. In that way, the solution enables citizens to report first-hand information and equips first responders with essential tools for early warning and response. Finally, it supports the decision making process at the municipality and government level (Aquobex Technologies, 2019; BRIGAID, ICRE8, &

[32] To read more about the LINKS foundation, its aims and projects, please consult their website: https://linksfoundation.com/en/

ICATALIST, 2020; EC, 2019; I-REACT, 2016; Rossi & Dominici, 2019)

Figure 2-4: Location of I-REACT in demonstrations

[***Figure 20****: Regional scope of i-REACT (Rossi & Dominici, 2019)*]

At the end of the project, the solution has been tested in multiple regions as depicted in Figure 20.

<u>4.1.3. Working of the cyber technologies at each stage & Feedback Loops</u>

The system structure of the i-REACT products developed and now offered by Aquobex technologies encompasses the following:

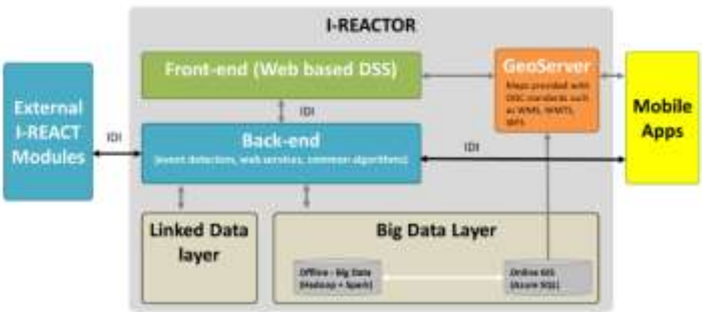


Figure 6-1: I-REACT architecture as defined in D2.7

[***Figure 21:*** *i-REACT system architecture Rossi & Dominici, 2019*]

i-REACT acts at all key phases of the emergency cycle. The following two figures show the Feedback Loop visualisation of the researchers (above, green) vs. the Feedback Loop visualisations of i-REACT (below).

In their own explanation, i-REACT visualises Disaster Management as follows, closely related to the researcher's interpretation of the DM cycle.

[***Figure 22-30****: Stages at which i-REACT acts explained in animations (I-REACT, 2016)*]

v

Furthermore, crowdsourced information shall be employed. This includes social media or reports from first responders and citizens using the React mobile application (I-REACT, 2016).

Through this integration and analysis of multiple data sources, areas at risk can be identified and monitored and finally, real-time warnings can be sent to citizens.

While sending real-time warnings already has a spillover effect, the crucial features that i-REACT can provide through the response stage are the following. First, it can integrate a multitude of information sources for monitoring and status assessment of an emergency, like fluvial flooding. Here, real-time reports from professionals, first responders and citizens are synthesised to improve positioning. This includes wearables that are included in the i-REACT package.

After the data is synthesised and analysed, it can be visualised on a live map at operational centres. Those are combined with Robotics automation (RA) like Unmanned Aerial Vehicles (UAVs) and, of course, satellite data if accessible.

To improve the reaction speed of first responders for whom this data is critical, smart glasses are provided to visualise augmented reality information and submit virtual reports. This data, combined with the above data, will, in turn, allow decision-makers at control centres to send real-time instructions to these responders or warnings to citizens.

Finally, the analysis and combination of all the data collected along with historical data, satellite and risk maps, weather forecasts, crowd-sourced reports and social media information will support decision-makers in taking correct and accurate actions during and after a flooding event. (I-REACT, 2016)

[***Figure: 22-30****: Stages at which i-REACT acts explained in animations (I-REACT, 2016)*]

4.2. Evaluation

4.2.1. Innovation

This was a highly innovative project, awarded numerous prizes in the category of innovation and effective use of cyber technologies. “Leveraging on innovative cyber technologies and ICT systems, I-REACT will be able to enable early planning of disaster risk reduction actions, achieve effective preparedness thanks to risk assessment and early warnings, and efficiently manage emergency responses by empowering first-responders with up-to-date situational information and by engaging citizens through crowdsourcing approaches and social media analysis” (EC, 2019).

The researchers also had the opportunity to discuss with a managing team member from Aquobex Technologies who was part of the consortium of the i-REACT project. Aquobex Technologies is currently further developing and selling the products developed in the 3-year-long project. The interviewee concludes that “the end product [...]was a great example of European collaboration, and we [i-REACT team] produced a next-generation multi-hazard early warning system that was far ahead of anything in the market place at that time” (PVT02, 2022). They furthermore explains that “it was a great piece of innovation in that it brought all types of natural hazards together in one platform and allowed 1st responders to see and react to events ahead of time. The unique use of social media as a two-way communication service with citizens during disasters is still world-leading” (PVT02, 2022).

4.2.2. Profitability

Costs

Aquobex, a UK company leading in the flood protection market, formed a new start-up, Aquobex Technologies, to sell the i-REACT solution in a B2B approach. According to a managing team member, prices are competitive. Recent prices for municipalities have low prices for the professional app and wearables per user per month (€5,- & €10,-), and higher prices for the Social media App per system per month (€5.750,-), control centre app and according to total control room cost (€750,- & €69.000,-) (PVT02,2022).

Introductory pricing 2019

END USER PRICING (s/w)

	per user/mo	Per system/month*	# users	per annum or one-off fee	Control room total cost p.a.
Basic I-REACT*		€ 2,000.00	1	€ 24,000.00	
Control centre App		€ 750.00	1	€ 9,000.00	
Data integration support		€ 3,000.00	1	€ 36,000.00	€ 69,000.00
Professional App	€ 10.00		10	€ 1,200.00	
Drone	€ 50.00		10	€ 6,000.00	
Glasses	€ 10.00		10	€ 1,200.00	
Wearable	€ 5.00		10	€ 600.00	€ 9,000.00
Social media App		€ 5,750.00		FOC	€ 78,000.00

[***Figure 31***: *Introductory pricing for 2019 for an example 10 user municipality in Europe (Personal communication, 10 June 2022)*]

4.2.3. Human Impact

The project has achieved great progress in connecting data sources and stakeholders. It is currently in the medium to large-scale commercialisation stage, offering its products to municipalities, other government bodies and NGOs. Furthermore, a managing team member at Aquobex Technology explains that “our focus has always been on the developing world and SIDS (South Island Development States) as these countries are most at risk of natural hazards and have the weakest early warning systems and citizen engagement” (PVT02,2022). However, challenges to scaling build a barrier to expansion to countries in the Global South, as will be explained in the following section.

4.3. Challenges, Expectations & Solutions

Rapid scaling of the solution was possible through a generous EC fund. The commercialisation of the project was undertaken in the private sector in the start-up Aquobex Technologies i-REACT. An interview the researchers conducted with a member of the Aquobex managing team gave great insights concerning challenges that were faced in the transition period to commercialisation and ongoing as well as future challenges and outlook regarding scaling.

Since Aquobex was part of the original Horizon 2020 project in the consortium, strong ties were developed early on with the developers, engineers and researchers. However, the interviewee states that “ the biggest obstacle we faced was the exploitation of the produced output” They furthermore explain that “the division of effort and reward should have been dealt with and settled at the beginning and not left to the end as it produced many rifts in the group” (PVT02,2022).

Hence the challenges are related to the complexity of such projects, including many stakeholders; the technological complexity, however, was no problem as “we had a great team of experts from across Europe” (PVT02,2022).

Nevertheless, the technological hardware that was used during the project proved unsuited for later commercialisation. The interviewee explains, “A problem with H2020 programmes that involve universities and other such government bodies is they tend to develop solutions on “free to use” or “student” software and hardware from the likes of Microsoft. Often these are years behind the current commercial levels of software release, and the hardware is also aged” (PVT02,2022).

The end result, while being a great piece of innovation, was outdated in its system architecture after the 3 years of the project. Here the interviewee refers mainly to the fact that a serverless solution and cloud-based applications should have been the end-product, not a hardware-based system. Furthermore, aspects like billing the customer were not considered in the original system architecture and proved to be a challenge in the commercialisation of the solution. However, at the end of the project, “Most of the I-REACT partners are not interested in following up the development and sales of the solution as their business models tend to be from government grant funding. A few of the partners are still engaged with us as we seek investment to update the solution to modern hardware and software” (PVT02, 2022). As advice to similar situations, the managing team member concludes that “In a similar situation, we would examine the proposed architecture in more detail up front, with our colleagues [...] with considering what the future would look like at the end of the 3-year grant" (PVT02, 2022)

Nevertheless, as other technological solutions are "catching up with us [Aquobex Technologies]" (PVT02,2022), the company is already looking to collaborate with some other start-ups in the USA "that we [Aquobex Technologies] can add value to with the product and our marketing ideas" (PVT02,2022).

Such collaboration could also help in overcoming another big challenge for the start-up: a lack of funding to update their solutions. The Aquobex Technology managing team member explained, "A lack of money [...] is preventing us from moving forward as it is an unplanned expenditure and needs to happen ahead of generating any sales revenue" (PVT02, 2022). They once again conclude that "If H2020 projects are to become commercially viable at the end, then this must also be the starting point" (PVT02, 2022).

Another crucial challenge was the inclusion of all stakeholders and end-users, especially civil society, in the design phase of the social media app. When asked whether a closer collaboration with civil society actors would have been helpful, an Aquobex specialist and former i-REACT consortium member agrees: "Absolutely, we should have had a civil response and first responders [...] in our consortium and not just as advisors." (PVT02, 2022).

Finally, in-depth market research of the addressable market, municipalities, governments, and NGOs was pushed to the end of the project. Two important aspects arose in the commercialisation stage. "In the developed world markets (e.g. Europe), the agencies had already invested millions in their systems so were not going to change wholesale. A piece-meal solution was required to add value to the existing systems" on the opposite spectrum: "In the developing world (e.g. Africa, Asia) infrastructure is a big issue along with ongoing maintenance. We should have included NGOs from these regions in our consortium too" (PVT02,2022). This led the interviewee to conclude that "we should have had [...] governments in our consortium [...]Our lack of understanding of their processes and practices was a major obstacle because the technology can only act as one element of their entire response and without a greater understanding of it we missed a trick and some sales" (PVT02, 2022)

However, this particular issue was tackled: "We successfully addressed these issues in the commercialisation stage, but that is where the upgrades to the software and hardware became the issue. The technological solution is still there today; it just needs reconfiguring" (PVT02, 2022).

Homa Reto - Participatory Mapping

Socio-technological solution

Organizational tool for civil society employing participatory mapping - web-based and mobile application

Prevention | Mitigation | Prepardness | Response | Recovery

(Images from https://homareto.com/)

Best-practice description

- The company aims to develop a participatory mapping software that should ultimately empower civil society
- Development of an organisational tool which empowers civil society members to coordinate needs and resources among different groups
- Increases accountability and ensures a certain quality and transparency in data gathering, analysis and visualisation

Innovation

- Bottom-up approach already in the development of the technology makes Homa Reto's application highly innovative.
- Increases accountability and ensures a certain quality and transparency in data gathering, analysis and visualisation

Profitability

- Company will employ a licence price modelling with a social background.
- NGOs and individual end-users can download the app at a reasonable price that is competitive.

Human Impact

- Challenges regarding inclusivity in the design phase are hence meaningfully addressed.
- "Ensures that such processes are "inclusive, efficient, and really cater to the needs of those who put so much work into it,those who are vulnerable"

Challenges, Solutions & Scaling

- "There is a lot of diversity and a lot of different perspectives [...] it proves a difficult undertaking to bring these actors together"
- Homa Reto is now in the process of finding investors to scale up their solution.
- What keeps the team going in this process is "a mission that makes sense to people [...] that is overdue and relevant" (Elaine Donderer, Founder and CEO of Homa Reto, 2022)

5. Recovery

Solutions like the above i-REACT are already doing a good job in including all stakeholders in the Disaster Management cycle. Furthermore, as explained in the emerging technology review in the conceptual framework, Volunteered geographic information (VGI), combined with GIS, can positively affect collaboration and coordination among volunteers, first-responders and official disaster agencies. However, conventional VGI focuses on gathering and including data from volunteers, civil society or first responders. Little focus has been on participatory mapping for humanitarian efforts in the Preparedness, Response and Recovery stage. Vermiglio et al. (2022) explain that humanitarian logistics, referring to mobilisation and management of resources (human and material), would be central to increasing resilience in the last stages of the DM cycle. Here Rodríguez-Espíndola et al. (2020) explain that "duplication of efforts for data input, multiple formats, lack of control of budgets, absence of accountability, lack of integrity in procurement procedures, absence of a central database, and manual reporting and tracking affect current DM systems" (as cited in Vermiglio et al., 2022). Reviewed Scholars Ragini et al. (2018) and Akter & Fosso Wamba (2019) point to the potential emerging technology like big data has to overcome such challenges.

Therefore, a novel approach to humanitarian coordination is needed. However, as mentioned, these technological solutions are very scarce. Nevertheless, the researchers of this report had the honour of being the successors of a research project that turned into a novel technology in this field: Homa Reto - The Human Network. Homa Reto is a recently founded start-up that is developing one of the first tools to organise civil society, for now in the Benelux area. The researchers had the unique opportunity to discuss the innovation with the start-up founder Elaine Donderer. The following review and evaluation of the technology are based on this interview and the company's website. While the company is still in the stage of developing the technology, so technically not in the prototyping phase, its novel approach to transforming a new industry of inclusion and coordination of the most vulnerable during disasters justifies it being selected as a best-practice socio-technological solution. Given that the company has not yet achieved the commercialization stage, the structural sections of the best-practice review will be slightly adapted.

Working of the technology and Human Impact

The company aims to develop a participatory mapping software that should ultimately empower civil society. While the focus of the interview was on flood disasters, it needs to be notest that while the focus of this review is flood disasters, it must be noted that the technology is developed with multiple purposes in mind: It shall "empower any kind of civil society that works towards sustainability, Inclusivity, racial justice and climate justice" (Elaine Dnderer, 2022) This inherently includes making (marginal) groups visible in a usually top-down area of disaster management.

This goal will be achieved through the development of an organisational tool which empowers civil society members to coordinate needs and resources among different groups. While social media has already paved the way to improved coordination among actors in civil society during disasters, there are still many flaws related to low-quality of data or lack of accountability (Haworth, 2016; es (Hung et al., 2016; Contreras et al., 2016; Schumann, 2018; Akter and Fosso Wamba, 2019; Sharma et al., 2020; PUB 2022). Here, Homa Reto van not only increases accountability and ensures a certain quality and transparency in data gathering, analysis and visualisation, but it wants to ensure that such processes are "inclusive, efficient, and really cater to the needs of those who put so much work into it [...], those who are vulnerable". In that way, Homa Reto's technology has the potential to transform the way one engages with civil society during and after disasters.

Output, Technological Development and Innovation

The concrete output is an app to be downloaded as well as a freely accessible web page. The software behind both the mobile application and the web page is being developed in close collaboration with the end-users. For a novice in the field of VGI and GIS in flood management, it seems natural that the inclusion of end-users of an application is included in the design process. However, in practice, this is hardly the case. This is confirmed by the previous case-study i-REACT. While their system design relies on VGI information, and hence civil society downloading and actively using their mobile application, they did not include civil society members or NGOs working with civil society in the design phase. As explained in the above case-study review and evaluation, this was one of the barriers to optimal implementation and scaling of the solution.

Hence, the bottom-up approach already in the development of the technology makes Homa Reto's application highly innovative. Elaine Wondered, founder and CEO of Homa Reto, confirms that "throughout our design process, we're in close collaboration with actors, really catering their needs" (2022). She furthermore explains: "We started with two years of research before even going into this [software application]". Not only that, but her whole team is involved in civil society movements and has a solid background in working with civil society actors - "we are no strangers to the community" (Elaine Donderer, 2022).

Once the mobile and web application is developed, the company will employ a licence price modelling with a social background. NGOs and individual end-users can download the app at a reasonable price that is not only competitive but can also spark wider societal adoption and hence scalability. For businesses, a higher price is negotiated (Elaine Donderer, 2022)

Challenges, Solutions and Scaling

While including end-users, here civil society, in the design phase, is essential for long-lasting success and sustainability in increasing resilience among the most vulnerable, it can at times be a two-edged sword that needs to be catered to with transparent communication, understanding and smart compromises. Founder of Homa Retro explains that "there is a lot of diversity and a lot of different perspectives [...] it proves a difficult undertaking to bring these actors together]. She furthermore explains the importance of recognizing these struggles in the development of the technology. Another challenge she reckons is related to the task of having to choose civil society organisations to work with in the first place "Because we're also people in the developer team, we're not just robots creating a software, we're also having our own opinions, experiences, networks. And it can be easy to slip into something that you've known, for example, or with these organisations I've worked before" (2022). She, however, lays great determination in reducing bias where possible and "making sure that really, also actors that are maybe unconventional, find their way into this".

Challenges regarding inclusivity in the design phase are hence meaningfully addressed. However, the start-up still faces institutional barriers to scaling. A conclusion that is not unlike the ones of previous case studies of Viridian Logic, Bufferblock and i-REACT is that collaboration and or investment through the public sector often proves more time-efficient and sometimes less rewarding than directing the same effort to private investors. However, the social start-up does not lack motivated team members or access to relevant research. "We have never had trouble getting research,, we never had trouble getting motivated students or universities on board". As CEO and founder of the company, Mis Donderer also plays great emphasis on a working culture that is rewarding and balanced for her team members. She explains that transparency in communication from the beginning is key.

Homa Reto is now in the process of finding investors to scale up their solution. Their design process is coming to an end this summer which is followed by a community feedback round. During that time, they will also be looking for full-stack app developers and build a team in the software development sector. After this process, a minimum viable product which will again be evaluated should be transformed into a first pilot for troubleshooting soon. What keeps the team going in this cumbersome process is "a mission that makes sense to people [...] that is overdue and relevant" (Elaine Donderer, Founder and CEO of Homa Reto, 2022)

Entrepreneurship Best-practices Discussion

The following section will elucidate key themes that reappeared during the meta-synthesis of the case studies in the Entrepreneurship sector. It will also give key insights into important discussions with Entrepreneurs that the research conducted. Finally, a summary table explaining in keywords which solutions have been found to challenges and which barriers to scaling still persist will be given.

<u>Small start-up, big impact</u>

According to market analysis (Emergen, 2022) of the Incident and Emergency management market, none of the best practices in this review can be considered large enterprises or global players in the sector of the global incident and emergency markets. Several potential reasons find their way together to this conclusion:

Collaboration for structural solutions

Even without operating on a large scale, case studies of the selected start-ups showed how working at the micro, or meso level can still bring, in some cases, even more benefits for communities in rural as well as urban areas. For example, while the start-up Bufferblock does not yet work together with national governments, their inclusive way of working in meaningful collaboration with their client municipalities has already shown huge successes. Viridian is a similarly successful case in which multiple stakeholders can bring in their opinions and expectations, and the inclusive modelling design finds the best compromise. While for Bufferblock, this was an engineered solution where design and implementation were considered together with the client, for Viridian, it was the technological modelling system itself that was inclusive.

Inclusion in design process

In the case of the above two examples, a bottom-up approach led to collaboration in implementing structural solutions. However, in the case of non-structural solutions focused on coordination, collaboration and communication among stakeholders during a disaster, end-users must be included in the design process in the development stage. There are two major arguments for this. First, the case study and interview with i-REACT admitted that without considering the end-user in the development stage, problems during commercialisation arise that not only impede sales but limit the potential resilience that could have been achieved if the solution were tailored correctly to the needs of those who are most vulnerable (PVT02, 2022). Secondly, the public and social sectors have repeatedly acknowledged a gap in communication and called upon innovation to bridge it (PUB01; PAP01; PVT01; PUB03; PVT03; SOC02). However, it is only possible to do so if all stakeholders are consistently asked for feedback and insights. In this way, the chances of all needs being addressed and misunderstandings being reduced are highest.

Social mission at heart

Another theme closely related to micro-level collaboration is the social mission that drives many of the selected start-ups and interviewed Entrepreneurs. All companies with a strong social mission were also most open to collaborating with civil society and the most vulnerable at the bottom of the disaster value chain. However, they are often the ones most affected and not involved enough in developing new technologies that can increase their resilience (PUB01; PAP01; PVT01; PVT02; SOC02).

A second benefit of having a social mission at heart is that it is incredibly motivating for teams, which is especially important in the start-up sector. Having a mission which people believe helps overcome adversity, problems of any sort and nature, including financial and institutional barriers (PVT01; PVT03).

However, there are limitations to the benefits of a social mission: it often means having to compromise more profits with sustainable or social production. It can also mean not finding enough investment due to the reluctance to compromise on the former. Nevertheless, most of the start-ups considered in the review achieved considerable success without having to compromise their social and human values (PVT01; PVT03).

<u>Private sector collaboration and investment</u>

Synthesizing the way in which start-ups achieved the scaling of their solutions, with expectations, most of it was concentrated in the private sector rather than private-public collaboration. While the public sector was a client of the companies, investment was mostly derived from the private sector. Entrepreneurs indeed found private investment easier to obtain (PVT01; PVT02).

Furthermore, many start-ups reviewed collaborated with other small and medium companies to achieve more impact and profitability together. Many also work together with established large private cooperations. However, due to a lack of interviews in this regard, it is unclear where the compromises lie when collaborating with large cooperations.

From research to practice

A final crucial consideration in the realm of start-ups is the background of the Entrepreneurs. They often come from an academic rather than a business background. This means technological development is often impeded not by a lack of knowledge or expertise but mostly by funding and business knowledge. Many Entrepreneurs call for increased support in scaling regarding simple institutional support like human resource management, tax burdens, and organizational tasks (PAP01; PVT01; PUB03; PVT03; SOC02).

	Viridian Logic	Bufferblock	i-REACT	FloodMapp	Homa Reto
Company Maturity	Small-scale commercialization	Small-scale commercialization	Medium and large scale commercialization	Medium and large scale commercialization	Development of prototype
Successful scaling in the past	Viridian Logical is a company developing modelling systems that are new in their approach to prioritise NBs - They are hence pioneers in the emerging market of NB modelling solutions.	Successful collaboration with more established companies in the private sector	Funded by EC, successful collaboration on technical aspects, highly innovative product at the time	Real life modelling with myriad benefits for civil society and governments alike Seed funding Collaboration with other start-ups	Highly motivated volunteers with a clear mission, rewarding work
Challenges to future scaling	Lack of visibility in the private sector and lack of recognition of NBs in general makes it difficult to achieve new clients and credibility. Funding Network New clients Visibility Partners Credibility	New clients Visibility Credibility - difficult to explain since there are many similar solutions	Lacking business and market analysis Lacking long-term commercialisation strategy after EU funding expired Lack of funding for updating and keeping up with new technological demands	New clients Visibility Funding, Technology is capital intensive	Network New clients Visibility Funding for R&D Partners Credibility

Diversion Canal, Detention Tank

Canal and tank store and divert excess stormwater from existing drainage in Orchard Road belt, Singapore

Cost-effectiveness	Feasibility	Equity
$ 227 million - One time investment costs lower than insurance claims and lost GDP due to pluvial floods	Centralised monitoring by Public Utilities Board ensured rapid and proper implementation	Benefitted high-income residents and low income workers employed in the region

Prevention | Mitigation | Preparedness | Response | Recovery

Rain Gardens

Strategically planted green spaces to capture and store excess stormwater and encourage percolation in Shenzhen

Cost-effectiveness	Feasibility	Equity
25% - 69% - Reduction in run-off from rain in Chinese urban areas due to rain gardens	Low maintenance after establishment, cleaning up and pruning required on occasion	Multiple value creation through creation of communal space, improved health among elderly

Prevention | Mitigation | Preparedness | Response | Recovery

Flash Flood SMS Warning

Use of SMS services to warn and prepare rural populations of incoming flooding in Terai regions, Nepal

Cost-effectiveness	Feasibility	Equity
US$ 0.20 - Cost of sending 100 SMS to mobile phone users in Nepal	Use of MoUs to rope in private telecom firms and local NGOs for preparing at-risk villagers	74% of Nepali population has access to mobile phones and SMS/call services

Prevention | Mitigation | Preparedness | Response | Recovery

Unmanned Aerial Surveillance

Utilising unmanned surveillance drones to assess flood damage and inform response in Fort bend, U.S.A

Cost-effectiveness	Feasibility	Equity
US$ 1,000 - Cost of unmanned aerial vehicle and associated software licence	Sufficient data can be captured in relatively short flight spans for a given location	Data can be used to make decisions to better prioritise the most vulnerable populations for rescue

Prevention | Mitigation | Preparedness | Response | Recovery

Bioswales

Use of sloped, vegetated drainage in social housing to improve drainage of excess rainwater in London, U.K.

Cost-effectiveness	Feasibility	Equity
1:4.39 - Cost to benefits ratio of bioswales and other green infrastructure in London	Possibility to retrofit swales based on current drainage infrastructure and built-up area	Focus on low-income social housing who are most vulnerable to pluvial flooding

Prevention | Mitigation | Preparedness | Response | Recovery

Diversion Canal, Detention Tank

Technological-engineered solution

Canal and tank store and divert excess stormwater from existing drainage in Orchard Road belt, Singapore

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description

- Diversion canal reduces pressure on existing drainage infrastructure
- Detention tank arrests excessive stormwater and slows down realease into drainage system
- Both systems work in tandem and save space as they are completely underground

Cost-effectiveness

- $ 227 million in investments and around 4 years for completion/operation

- Total cost of investment is lower than long-term aggregate of insurance claims

Feasibility

- Construction under densely built areas is costly and requires constant monitoring of soil conditions to determine risks and stability before during and after construction
- PUB is a centralised agency which manages all aspects of water so it has the technical capacity to implement complex engineered solutions

Equity

- Beneficiaries of the Stamford Diversion Canal and Detention Tank were largely from the Bukit Timah and Tanglin region and faced a high level of flood risk
- Low-income workers were indirect beneficiaries due to reduced job loss

Challenges, Solutions & Scaling

- A single large detention tank will not be able to, in isolation, handle excess stormwater and alleviate pressure on drainage systems

- A government has proactively introduced a policy mandating the construction of small detention tanks to store stormwater in all new developments and redevelopments with an area larger than 0.2 hectares

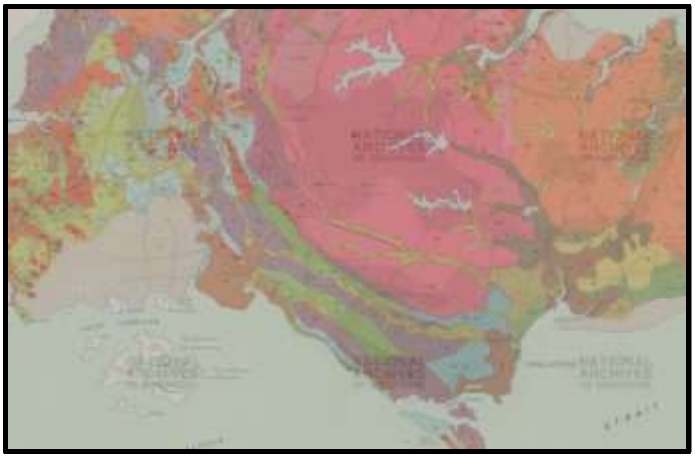
Public - Report of Best-Practices

1.Prevention

1.1 Innovative Engineering Solution

1.1.1. Background & Relevance

Singapore is a low-lying city-state in Southeast Asia characterised by a tropical rainforest climate with very high precipitation year-round. Singapore's relatively flat geography makes it prone to pluvial flash floods caused by intense rainfall events in a short time period (Kennedy, 2015). Singapore has developed and urbanised rapidly since its Independence in 1965. The gradual replacement of relatively undeveloped villages known as *kampongs* with high rise public housing estates and industrial and commercial spaces increased the proportion of non-permeable surfaces such as that of tar roads and concrete. The increased urbanisation is associated with increased generation of run-off water from rainfall leading to inundation as the non-permeable concrete and tar do not let water drain naturally nor percolate into the ground water table/aquifers (Feng et al., 2021).



[***Figure 1:*** *Geological Map of Singapore [Kallang Formation in Yellow] (Department of Scientific and Industrial Research, 1977)*]

The Orchard Road belt is one such developed region and is one of Singapore's important retail and commercial spaces. This region is part of the Kallang Geological formation which consists of predominantly clayey soils along Singapore's various river valleys and plains (Cai, 2012). The type of clay mostly found in the Kallang Formation is marine clay. This type of clay has relatively low vertical and horizontal hydraulic conductivity. Hydraulic conductivity refers to the ability of water to be able to move through a porous medium in either a vertical or horizontal direction. Marine clay in Singapore has relatively finer grains and is thus less porous. The effect is thus that it has a substantially lower degree of permeability and drainage ability in comparison to other soil types (Arulrajah & Bo, 2008).

[***Figure 2:*** *Map of Singapore Flood Prone Areas (Public Utilities Board [PUB], n.d.)*]

Referring to the above figure, the Orchard Road belt lies in a blue shaded region between the points labelled as Bukit Timah and Jalan Besar. In comparison to Figure 1, the Orchard Road belt clearly appears to coincide and lie along the Kallang Formation. Given the poorer drainage of marine clay, the Orchard Road belt was among the regions in Singapore identified as flood prone areas in the 1970s by the PUB (n.d.).

To improve drainage in the region, the PUB previously constructed an open diversion canal along the Bukit Timah region which was completed in 1991 (Kennedy, 2015). This engineered intervention has proved successful as similar interventions have been carried out by the PUB across the main island. The areas affected by floods in Singapore have therefore decreased from 3200 hectares in the 1970s to 30.5 hectares in 2016 in part due to the construction of diversion canals by the PUB (PUB, n.d.). Despite this success, Singapore is vulnerable to climate change. Current trends in Singapore point towards increased annual rainfall in Singapore and an increased frequency of heavy tropical storms over the next few years (Kennedy, 2015). Singapore's Ministry of Sustainability and Environment [MSE] has invested in expanding existing diversion canals and constructing newer diversion canals to improve drainage and reduce the underlying risk of pluvial flash floods caused by heavy rain (MSE, 2020).

1.1.2 Justification

The prevention stage involves planning and designing cities to reduce the chance of a disaster occurring in the future. This means to directly reduce the chance of a flood occurring even in a context where climate change increases risks and vulnerabilities (UCF, n.d.). The case could potentially be treated as two separate cases, one for the detention tank and one for the diversion canal. However, these two technologies actually work in tandem with each other to manage pluvial flash floods in the Orchard Road Area (PUB [sgPUB], 2018). Thus, it would be beneficial to analyse them as a single solution. It also reflects that engineered solutions cannot be a cure-all for flooding but can work with other structural and non-structural measures to reduce flood risks (PAP01, 2021).

Detention tank technology is not a novel innovation of recent times. Detention tanks in the form of artificial lakes and temple tanks have formed the core of the water management systems in the Tamil Nadu state of Southern India. It is known as the *eri* system (Perundevi, 2019). The *eri* system also makes use of diversion canals to drain tanks before they exceed their capacity by cascading and conveying excess water into a tank further downstream. This therefore reduces the chance of flooding overflowing either the canal or the tank as long as it is maintained. The system is able to successfully capture stormwater thereby preventing pluvial flooding. The *eri* system has been on the surface and thus takes up large areas in the outskirts of cities in the region. This led to the encroachment of water bodies during urban expansion in the city of Chennai and thus led to competition for diverse land use ranging from housing, institutional uses, industrial areas and commercial areas (Nithila Devi et al., 2020) The innovative aspects of the Stamford Diversion Canal and Detention Tank is that it is built entirely underground and does not conflict with densely built land use in Singapore. It is potentially applicable in many other coastal urban areas globally (MSE, 2020)

1.1.3. Best-practice Description

A diversion canal reduces the downstream water level of a river to compensate for the lack of conveyance capacity of a given river. The diversion of exceptional flooding events is not possible through a diversion canal unless it connects directly to the ocean and has sufficient conveyance capacity to move the large volume of stormwater (Tourment et al., 2016). The conveyance capacity refers to the ability of a given river or canal to discharge water and has a significant influence on water levels, especially during floods (Environment Agency, 2019)

The Stamford diversion canal diverts water from the upstream Stamford Canal to the Singapore River further south in an effort to reduce the drainage strain on the existing canal (MSE, 2020). The canal is around 2km long and 4.5m in diameter. It connects to the Marina Reservoir through the Singapore river to relieve the pressure on the Stamford Canal. The canal is relatively shallow and is as high as 4m below surface level and involved careful tunnel boring in densely built-up areas such as Grange Road (PUB, 2018)

The detention tank has a capacity of 38,000 m^3 and covers 0.5 hectares of land. It stores excessive stormwater thereby regulating the flow of water into the diversion canal. The tank can be emptied by pump in a period of 4 hours to drain stored water into the diversion canal after a heavy spell of rain to prepare for the next possible flood. This further aids with reducing the pressure on existing drainage infrastructure in densely built-up land areas (PUB, 2018).

[***Figure 3:*** *Animated Map of Stamford Diversion Canal and Detention Tank (PUB, 2018)*]

[***Figure 4:*** *Stamford Diversion Canal Tunnel after completion (MSE, 2020)*]

[***Figure 5:*** *Stamford Detention Tank after completion (MSE, 2020)*]

1.2. Evaluation

The diversion canal and detention tank work in tandem to prevent pluvial flooding in a highly commercial region thereby significantly reducing annual economic losses. The project is feasible but only cost-effective for densely-built commercial belts as seen in Asian cities. Despite its niche application, it is indeed a useful solution to consider for implementation.

1.2.1. Cost-Effectiveness

The entire intervention cost the PUB around Singapore Dollars [S$] 227 million (United States Dollars [US$] 162.22 million) in financial investment from the government and a time span of 4 years for complete construction and to begin operations in 2018 (MSE, 2020). The Orchard Road Belt lies in a depression and is more prone to flooding due to its low elevation. This led to historically preventative measures such as the widening of the original Stamford canal to improve conveyance capacity as well as to convert drains in the region to better convey water away from the area. However, increased precipitation has led to more flooding since 2010 (Tortajada et al., 2021).

Orchard Road is Singapore's main retail high street. Thus, it attracts a large number of overseas visitors annually and is strategically important as a business and retail hub employing a substantial proportion of local and foreign workers who flock to Singapore. This therefore generates important revenue for the government and an important source of income for many. Flooding in 2010 led to S$ 23 million (US$ 16.4 million) in insurance claims, with similar claims requested the following year in 2011. In addition to damage to infrastructure, many local businesses were forced to close, increasing the costs of operation and expenses on welfare. Flood risks worsened Singapore's position in an increasingly competitive environment as Asia's economy booms. The most recent major flood event in 2015 saw a higher amount claimed for flood insurance with an estimated total claim of S$ 25.3 million (US$ 18.8 million). These costs which appeared to be increasing with each flood event and with the increased risks of these events occurring, preventative measures became essential. Thus, the large one-time investment will pay off in the long-run (Tortajada et al., 2021; Chow et al., 2016). Given that the Orchard Road belt is no longer classified as a flood prone zone by the PUB, the project could be deemed as effective (PUB, n.d.).

1.2.2. Feasibility

Construction under densely built areas is relatively expensive and requires constant monitoring. Given the softer marine clay in the region, soil conditions had to be monitored constantly to determine risks and stability before, during and after construction of the canal and tank (Bhaskaran, 2019). The PUB is a public agency that is highly experienced with retrofitting grey infrastructure in built areas and thus was able to provide the necessary technical expertise for the construction of the canal and tank (PUB, 2018).

Sudden flash flooding in Orchard Road has also sent shockwaves in the public, leading to the involvement of local politicians. This allowed the PUB to be able to push for an upgrade in drainage infrastructure around Orchard Road and was able to obtain the required investments to reduce flood-risks in the area. Preventative measures, especially structural measures are usually prohibitively expensive for a government agency to invest in. However, given the intervention was on a local scale, it was naturally easier to implement as fewer stakeholders were involved. Additionally, given that the infrastructure was largely underground, it distrubed fewer residents and businesses, keeping the circle of affected stakeholders relatively smaller than most other projects (Tortajada et al., 2021; PAP01; PUB, n.d.).

Finally, the PUB is Singapore's centralised water agency. This means that it is the agency that has the mandate over all aspects of Singapore's water management, ranging from drainage, sewage treatment, flood-management, water recycling and water storage. This gives the agency substantial power to invest in grey infrastructure which can serve multiple purposes beyond flood-management. For example, the water captured will drain into the Singapore river which is ultimately caught by the Marina reservoir and contributes to Singapore's drinking water resources, reducing its dependence on imported water from neighbouring Malaysia (Tortajada et al., PUB, 2018).

1.2.3. Equity

As this grey infrastructure targeted a particular part of Singapore, most direct beneficiaries of the canal and tank were residents in the Bukit Timah and Tanglin areas, who had previously faced higher levels of flood risk in comparison to residents of other housing estates across the island (PUB, n.d.).

It could be argued that Singapore's more well off upper-class were the only beneficiaries of the reduced flood risk as Bukit Timah and Tanglin have markedly lower incidences of poverty than the median housing estate in Singapore (PUB, n.d.). Households here have very high median incomes compared to most estates and a very large proportion of the local population lives in private housing, which is not common across most other estates in Singapore. Higher income Singaporeans are more likely to be able to afford more comprehensive insurance or pay for damages to personal property due to floods. Thus it may initially appear that a relatively more resilient section of Singapore's population may have benefitted from the structural measure (Lee et al., 2021).

However, many more of Singapore's financially vulnerable members indirectly and directly benefited. Firstly, Orchard Road's retail centres attract heavy foot traffic. Thus, many of Singapore's poor have taken advantage of this foot traffic to earn a living. Buskers are common with around 14 designated busking spots licenced by the government along Orchard Road. Thus, they are directly dependent on the district remaining open to make their daily living. This also further includes the community of hawkers who usually sell food out of (licenced) pushcarts to foreign tourists (Zainal, 2012)

Orchard Road's retail sector is large and thus employs a large number of service workers. These include individuals who work in cleaning, sales workers, service agents and clerks. These jobs are relatively common, but do not pay much in comparison to more technical jobs for officers. The median monthly income for service workers ranges from S$ 1,638 (US$ 1,170.54) to S$ 2,598 (US$ 1,856.56) depending on their job and place of employment. This is well below the national median monthly income of S$ 4,680 (US$ 3,344.39). A disproportionately large share of these lower income workers are foreigners who face lower wages, higher costs of living and must support families overseas (Manpower Research & Statistics Department, 2022). Therefore, while direct beneficiaries are from more resilient sections of society, more vulnerable members indirectly benefit, particularly in economic terms due to the reduced loss in employment days and thus incomes.

1.3. Barriers, Expectations and Solutions

While the structural measures taken by the PUB appear to be successful, some key challenges remain. Firstly, in the long-run a single large detention tank will not be able to handle excess stormwater. In the context of an increasing risk of pluvial flooding due to upward trends in precipitation, existing drainage systems will face increased pressure. To alleviate the future pressure on such structural systems will require a long-term non-structural and structural plan (Bhaskaran, 2019; Kennedy, 2015). The PUB has already proactively introduced a policy to mandate the construction of smaller detention tanks in all new developments or redevelopments with an area larger than 0.2 hectares. As Singapore's urban areas continue to expand, these detention tanks can increase a land parcel's ability to capture stormwater and release it in a more regulated and manageable way. The inclusion of redevelopments is strategic as many new developments in Singapore occur in already densely built areas which are demolished and rebuilt due to land constraints (PUB, 2018).

Singapore's investment in preventing floods and long-run policy to mandate continued structural interventions through the creation of an extensive network of small detention tanks could have a potentially mitigating effect on flood-risk. While the diversion canal and detention tank work in tandem to prevent inundation by improving drainage, as flood-risks rise due to climate change, the additional detention tanks will have the capacity to further reduce drainage pressure by storing more stormwater and thus minimising any damages to the existing infrastructure. This becomes a unique feedback loop where a structural measure that aims to prevent floods also has the potential to mitigate flood damage in the long-run.

Rain Gardens

Nature-technological Solution

Strategically engineered green space to capture and percolate stormwater

Prevention Mitigation Prepardness Response Recovery

Best-practice description

• Pilot is Guangming District of Shenzhen city in Southern China

• Plants used to mimic flood-management and water purification services of wetlands

• Implemented in multiple built-up areas to improve drainage in densely populated areas

Cost-effectiveness

• Up to 71% decrease in peak overflow from heavy rainfall and 69% reduction in run-off generation

• RMB 1.5 billion funding from public-private partnership with municipality

• Over 200 flood points in Shenzhen city were eliminated

Feasibility

• Relatively lower costs of construction and maintenance compared to grey structural measures such as canals

• Unified water authority allows for streamlined implementation in Chinese cities

Impact

• Can be implemented in both medium to high density areas across multi-income neighbourhoods

• Positive effects on health among vulnerable elderly and poorer populations

• Possibility of income generation from tourist activities and cultural attractions

Challenges, Solutions & Scaling

• Land acquisition is usually the biggest expense

• Over-dependence on public sector intervention and funding heightens opportunity costs

• Feedback loops leads to parallel effects improvements in mitigation and recovery

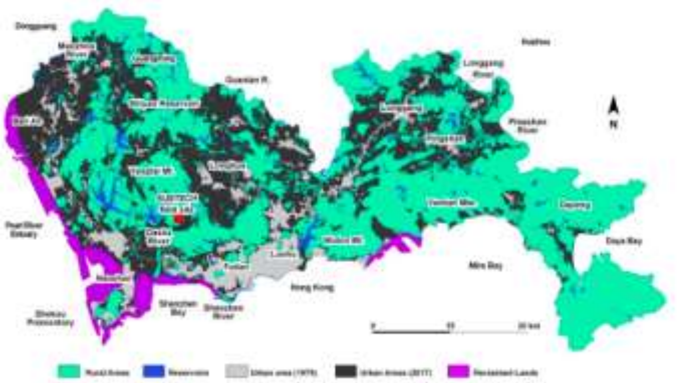
2. Mitigation

2.1 Nature-technological solution

2.1.1. Background & Relevance

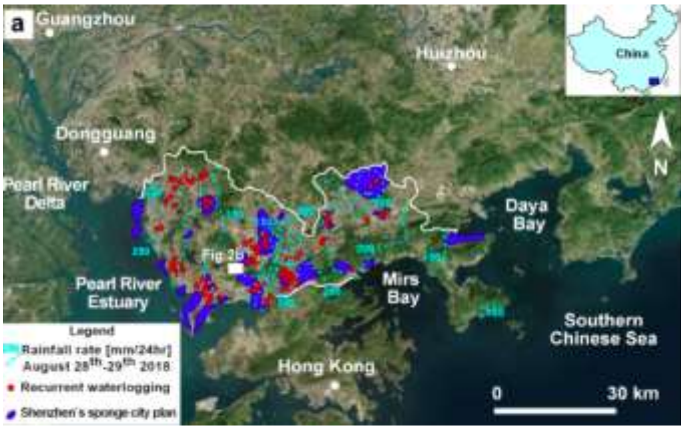
The People's Republic of China has suffered from repeated flooding throughout its long history. This has led the national government to invest in low impact development in its cities as part of the Sponge City Scheme. Of the 654 cities in the country, 641 are flooded on a frequent basis making this scheme of national importance (Song, 2022). China's rapid economic growth, especially along its coastal cities in the East has worsened flooding in its urban areas. The country's urban population as a proportion of the total increased substantially from 49.68% in 2010 to 63.89% in 2020. The total urban population expanded to 901,991,662 people which is an increase of 236,415,856 individuals over a decade (National Bureau of Statistics, 2021). The massive population growth in its cities led to the expansion of built-up land. Between 1990 and 2010 China lost 2883 km^2 of wetlands due to urban expansion. Much of this loss (2394 km^2) occurred in the Eastern half of China (Mao et al., 2018). Increased built-up area in cities leads to increased urban run-off which can cause or contribute to floods as they have lower capacity to hold onto stormwater or percolate it into the groundwater table (Chan et al., 2018; Song, 2022).

China has had a history of using preventative engineered measures to manage floods including building over 97,000 dams since 1950 for irrigation and flood-management. However, these solutions only pertain to fluvial (riverine) flooding and do not holistically manage floods/water (Chan et al., 2018; Qi et al., 2020). China will face more extreme weather patterns over the next few decades. By 2050, the number of heavy precipitation days will increase by 14 to 20 days and monsoons may start earlier than usual increasing the risk of floods. Shenzhen, one of China's most important port cities, in particular faces a higher risk of typhoons (storms) (Dai et al., 2022; Qi et al., 2020)



[***Figure 6:*** *Shenzhen Temporal Landuse Map (Lancia et al., 2020)*]

Shenzhen is a city in coastal Southern China with over 17 million residents. It has historically been one of China's fastest growing urban centres (Wang et al., 2022). Shenzhen is often seen as a sign of China's rapid economic growth as the fishing village mushroomed into a megacity and economic hub, swallowing rice fields and wetlands. From the above figure, the area categorised as 'urban' in 2017 (in dark grey) is much larger than the urban area for 1970 (in light grey), a spatial visualisation of the rapidity of urbanisation. Shenzhen's rapid urban growth over 40 years has decreased the cover of marshes and wetlands leading to over 446 points recognised as prone to flooding in 2016.



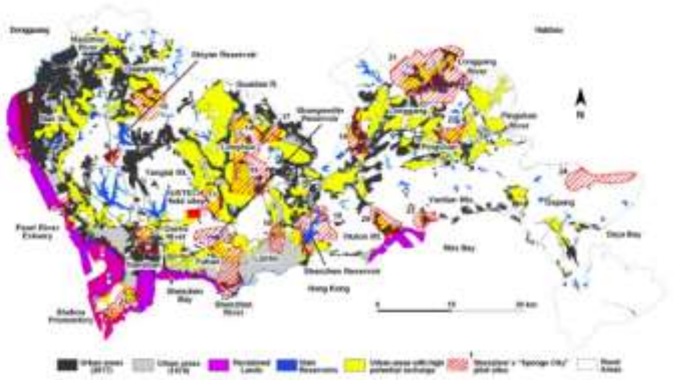
[***Figure 7:*** *Map of Flooding Points and Sponge City Interventions in Shenzhen (Lancia et al., 2020)*]

Based on Sponge City Programme Targets, Shenzhen needs to ensure 312.17km^2 of land that can absorb water (United Nations Economic and Social Commission for Asia and the Pacific [UNESCAP], 2021). Shenzhen's drainage infrastructure is not well coordinated compared to other cities such as Singapore and remains relatively underdeveloped. This leads to more water contamination and the creation of new flooding points, increasing the number of people at risk of flooding (Wang et al., 2022).

As seen in the above figure, the city receives relatively higher volumes of rainfall due to its coastal, tropical location. This naturally increases its risk of flooding given the high proportion of built-up land. Comparing figures 6 and 7, it is noticeable that points of recurrent waterlogging tended to coincide with the most heavily developed urban land. Thus, the Sponge City interventions also reflect this pattern to some extent (Lancia et al., 2020).

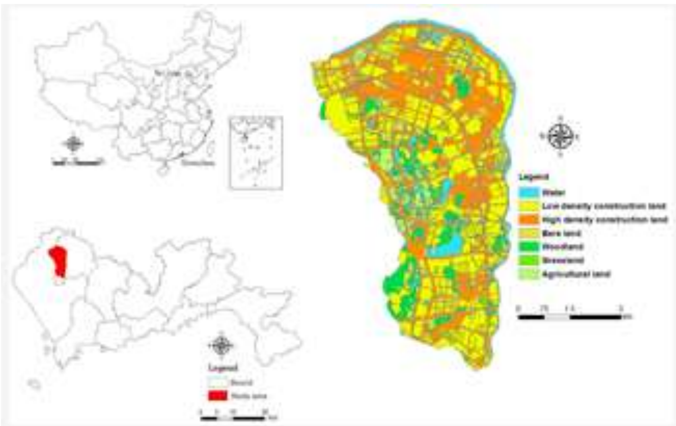
2.1.2 Justification

The Sponge City Programme aims to improve the spatial planning in Chinese cities to adapt to China's increasing risk of pluvial flooding caused by climate change. As part of this national policy, a variety of solutions have been implemented and are slated for completion to improve the drainage of cities. Nature-based solutions feature often in city plans. One such commonly used flood mitigation solution is the rain garden (Song, 2022). The aim of the rain gardens are not to prevent flooding altogether but rather minimise its impacts by detaining excess stormwater and improving groundwater recharge in built-up areas. Hence, it aims to reduce the impacts of a pluvial flood when it occurs and is thus mitigative in nature (UCF, n.d.; Song, 2022, Dai et al., 2022).



[***Figure 8:*** *Map of Land Use Potential and Sponge City Sites in Shenzhen (Lancia et al., 2020)*]

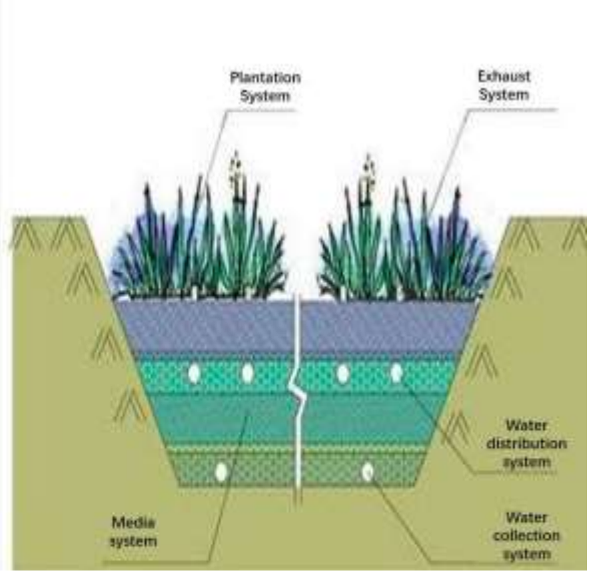
Shenzhen and other Chinese cities' drainage infrastructure often face excessive pressure due to large volumes of generated run-off. Rain gardens and other nature-based solutions help curb run-off generation through water retention and direct groundwater recharge thereby reducing pressure on man-made drainage systems in cities. The Sponge City Programme aims to increase absorbent land area in cities by 20% and is hence a retrofitted solution. It also aims to capture 70% of all storm run-off. This further aims to reduce flood-risk by aiming to minimise damages caused by flooding rather than preventing the occurrence of a flood altogether (Chan et al., 2018; Song, 2022). This becomes a particularly important consideration when flood risks are increasing at a rapid pace relative to the ability to come up with preventative structural measures forcing the public sector and the population to adapt to remain resilient to this new normal caused by climate change (UCF, n.d.). Shenzhen is largely covered by clayey soils which are less permeable. This is largely due to Shenzhen's position along the coast close to the Pearl River Delta. This makes permeable pavements a poor solution as the clay must be partly replaced with more permeable soils (Jenkins, 2020). Observing the above figure, it is observable that a large proportion of urban land has good potential for drainage and percolation of water underground, reducing the risk of waterlogging. Many Sponge City pilot sites also coincide with these regions indicating the public sector's intention to make best use of land use planning to achieve a larger drainage effect.



[***Figure 9:*** *Location and Land Use Patterns of Guangming district, Shenzhen (Wu et al., 2018)*]

Guangming district is one of the divisions of Shenzhen and was chosen as one of the key sites for the Sponge City Programme in Shenzhen. It is located inland toward the northwestern part of the city in an area of higher elevation than along the coast. The district is 37.68 square kilometres and 69.8% of its area is covered by impervious surfaces such as roads and concrete. Most of the developed lands are of low to medium density while a substantial proportion have a high population and building density. It now serves as an example that can be emulated across the country by other cities (Wu et al., 2018).

2.1.3 Best Practice Description



[***Figure 10:*** *Illustration of Rain Garden mechanics in Guangming District, Shenzhen (UNESCAP, 2021)*]

Rain gardens are strategically constructed green spaces which have the capability of collecting excess stormwater, percolating it to the ground and partially purifying or treating it to improve water quality. It mimics the ecosystem services typically provided by wetlands in coastal regions by doubling as a form of flood mitigation by capturing water as well as improving water quality in the surrounding areas. Firstly, the area that is to be converted into the garden is slightly excavated to create a sloping design and strategic depressions to aid the conveyance and collection of water. The collected water is then connected to the water table naturally or through the aid of percolation wells. Given that bare soil is relatively unstable and can worsen pollution by releasing particles into the collected water, native plants which are resilient to both drought and inundated conditions are planted such as those of the *Typha* genus. The plants typically help hold the soil together to prevent erosion and slow down the flow of water to ensure it is more likely to be stored and percolated. They are also able to remove traces of heavy metals from the water which is a major issue in Chinese urban areas due to the extensive manufacturing sector and the associated pollution (Song, 2022).

The Sponge City programme aims to reduce peak water discharge, reduce excess stormwater through upgrading infrastructure to improve resilience and integrate natural and artificial blue and green spaces to adapt to floods using nature (Chan et al., 2018). Rain gardens were the most commonly cited nature-based solution associated within the Spong City Programme in the Chinese National Knowledge Infrastructure Database in part due to their versatility (Song, 2022).

Rain gardens and other nature-based solutions have the potential for multiple value creation within and beyond water management. In addition to mitigating flood-risk, rain gardens can purify water and improve ground water tables which can increase the availability of clean water in periods of drought. Given that many Chinese cities face increased water stress, this additional benefit would be particularly important to ensure sufficient access to water. It can also act as a site for touristic and leisure purposes thus forming a communal space (Chan et al., 2018; Song, 2022). Plants used in rain gardens are typically resistant to water logging as well as periods of droughts. They can also resist substantial levels of water flows. Usually native plants matching these criteria are typically used although occasionally alien/foreign plants may be introduced to enhance the function of the rain garden (Zhou et al., 2020).

[***Figure 11:*** *Illustration of Rain Garden Plan (Song, 2022)*]

2.2. General Evaluation

The rain gardens in Guanming district have substantially improved the retention of stormwater to mitigate the damages of pluvial flooding in an increasingly wetter climate. However, it competes with other forms of land use. Nevertheless, it is a multi-functional solution that can mitigate pluvial flooding and improve water-management in coastal, densely populated cities and is replicable globally.

2.2.1. Cost-effectiveness

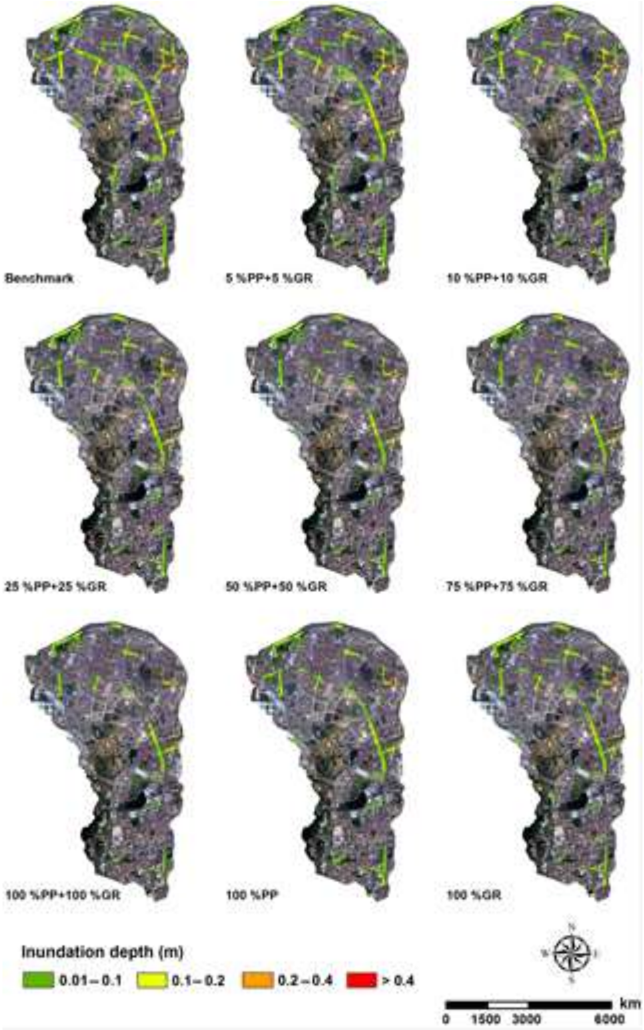
Rain gardens are a relatively versatile solution because of their employment of biomimicry to provide ecosystem and flood mitigation services similar to that of a wetland. Given that there are different wetlands in different climatic regions, rain gardens can be adapted to these conditions by using native vegetation which are best evolved for the local climate. In addition to climate, rain gardens can also be designed for local soil conditions based on their ability to drain water, whether they are more acidic or alkaline and their general moisture content (Song, 2022). Given Shenzhen's clayey soil profile, rain gardens are likely to have deeper sections replaced with more permeable soils to better encourage percolation and drainage (Song, 2022; Jenkins, 2020). One key limitation however is that they cannot be used in areas with a high water table or where the aquifers are close to the surface as percolation will not occur as there would be insufficient depth. They also may not be the most effective to handle areas with scanty rainfall or particularly prolonged drought-like solutions (Song, 2022).

Economically speaking, rain gardens are highly beneficial. Firstly, in comparison to most structural grey infrastructural solutions, they have much lower maintenance and construction costs. This is because rain gardens do not require too many materials to construct and mostly make use of local soils and on occasion a geo-technical reinforcement such as stones and fibres. Additionally, the costs of plants are not too high such that a local municipal level authority would not be able to invest in a rain garden (Chan et al., 2014). Combined with relatively lower construction and maintenance costs, there is the chance for multiple value creation. Firstly, rain gardens can absorb the impact of pluvial floods and accumulate the water before it can damage buildings or other infrastructure, thereby reducing repair/recovery costs. Additionally, they are able to partially filter or treat water which reduces the costs of setting up water filtering or processing centres by the public sector or private entities. The encouragement of percolation of water to the ground water table ensures aquifers are replenished and clean water is available especially in times of drought when surface water may be unavailable.

[***Figure 12:*** *Completed rain garden in Guangming District, Shenzhen (UNESCAP, 2021)*]

Finally, rain gardens, especially in built-up urban areas have the potential to become tourist attractions and thus allow the municipality to directly generate revenues. Overall, rain gardens are able to reduce general stormwater run-off by between 25% to 69%. In addition, peak run-off can be reduced by between 12% and 71% (Song, 2022). As observed in figure 11, the aesthetic appeal of rain gardens are clearly visible. Especially those strategically placed among other green infrastructure near residential areas can greatly uplift the surroundings while also remaining functional (UNESCAP, 2021).

Overall, Shenzhen municipality has invested a total of between Renminbi [RMB] 5 billion (US$ 746.8 million) to RMB 7 billion (US$ 1.05 billion) to acquire land for all the implemented Sponge City Programme initiatives. This is around three-fold higher than the budget the municipality received from the Chinese Central Government of RMB 1.8 billion (US$ 268.8 million). This was predominantly because of the high population in Shenzhen which had driven up the land prices in the region compared to other cities in China (Jenkins, 2020). The municipality however was able to sustain the effort by involving other stakeholders in the funding process to reduce the financial burden on the public system. A public-private partnership mechanism was used to raise around RMB 1.5 billion (US$ 239 million) in funds for the Sponge City Initiatives for the Guangming district including the rain gardens (Wang et al., 2022). This allowed the Guangming district to invest in green infrastructure. While the upfront costs seem high, much of these costs were incurred due to land acquisition as the rain gardens were retrofitted. These would be much lower if they were already integrated ahead of development in land use planning. While the rain gardens function well, they are currently not fully connected to drainage from the built-up areas of Guangming district. This means that some stormwater run-off fails to reach the rain gardens entirely due to the existing drainage system. In general as more land is dedicated to rain gardens, the lesser run-off is generated as there are more permeable surfaces. However, this marginal decrease in run-off generation peaks and decreases and thus the area dedicated to rain gardens need to be modelled and checked prior to implementation to ensure optimal solution delivery (Wu et al., 2018).



[***Figure 13:*** *Simulation maps for Inundation with different Green infrastructure and sponge city scenarios for Guangming district, Shenzhen (Wu et al., 2018)*]

2.2.2. Feasibility

Rain gardens are often implemented using public-private partnerships which can spread the costs across stakeholders. This reduces the budgetary pressure and fiscal push required from the public sector given that any public sector expenditure involves higher opportunity costs due to many alternative allocative possibilities (Song, 2022).

Rain gardens are relatively easy to maintain after their establishment. Usually, the drainage within the garden needs to be cleared of plant debris or soil/silt deposits on a regular (monthly) basis. Additionally, the vegetation may require an occasional trimming to ensure the maintenance of drainage capabilities as well as to preserve the garden's aesthetics. The labour and technology involved are relatively inexpensive and the costs can be distributed across local beneficiaries of the rain garden (Chan et al., 2014).

The rain garden can also be integrated with the rest of the drainage infrastructural network to serve a larger area. This has already been implemented in cities such as Singapore (Song, 2022)

[***Figure 14:*** *Rain gardens integrated in new construction plan for Arts Centre in Shenzhen (UNESCAP, 2021)*]

Shenzhen, like Singapore, has a single water authority which coordinates all levels of water management. These include stormwater capture , drainage, wastewater treatment and reuse as well as flood management. This allows the public sector to develop solutions that can retrofit existing structural and nonstructural measures that work in tandem with existing infrastructure rather than in a siloed and isolationist manner. Thus, rain gardens can be more seamlessly integrated in Shenzhen's future land use plans and be tuned to suit local needs (Shenzhen Municipality, n.d.).

2.2.3. Equity

One effect of the multiple-value creation is the improved water quality in water bodies across Shenzhen. Many rivers have become habitable for fish again as observed across downstream areas in Shenzhen after the implementation of rain gardens (UNESCAP, 2021). The rain gardens' ability to purify water by removing around 54% of suspended solids in water. Certain plants such as the *typha* genus can extract heavy metals from water (Zhou et al., 2020). This could substantially improve access to clean water in Shenzhen as well as the wider Pearl River delta. This means that large sections of the population which were previously vulnerable to water scarcity may now be able to better access water due to increased availability of clean water.

Low-risk and medium-risk inundation can be reduced through rain gardens and other similar LID infrastructure. However, at a high-risk it is not too effective (Wu et al., 2018). In this regard, Shenzhen has been able to eliminate flooding in 220 points across the city. The lower the level of pluvial flooding the easier it is for the general public to continue economic activities without interruption and the less likely that a flood would cause major disruptions which would disproportionately affect lower income persons (Wang et al., 2022).

The Shenzhen municipality has worked with the private sector to fund and implement sponge city projects all over the city ranging from new infrastructure in less developed regions or retrofitted infrastructure in densely built business districts (The Nature Conservancy, n.d.). The Shenzhen municipality is also making use of collaboration with the private sector and civil society organisations to better include the everyday citizen in the process of implementing the Sponge City initiative. The public sector has also allowed The Nature Conservancy to conduct a policy evaluation independent of the public sector to more transparently measure the impacts of Sponge City initiatives. In the long run, greater civil society involvement could also improve the maintenance of rain gardens and public awareness of the function of green infrastructure (The Nature Conservancy, 2017).

Increased green spaces such as rain gardens have substantial positive effects on public health, especially for eldelry populations. Previous studies have shown that lower income populations at a higher risk of poor health have lower access to green spaces. Rain gardens could improve access to green spaces while also reducing the damage caused by pluvial floods in low income areas. Given China's rapidly ageing population as well as high levels of inequality, these additional non-flood related benefits may make vulnerable sections more resilient in the event of a flood as better health would entail faster physical recuperation after a flood event (Cilliers et al., 2021).

2.3. Barriers, Expectations and Solutions

Transferability of rain gardens across municipalities is a major challenge in the widespread implementation of rain gardens. Shezhen is a relatively well-off municipality within China and has a wetter climate than inland regions making rain gardens more suitable for Shenzhen. This means that rain garden strategies in Shenzhen may not be easily applied to areas further inland which have a dried climate and lower risks for pluvial flooding compared to fluvial flooding. However, the government has already piloted the Sponge City Programme in a variety of different environments. This would allow other municipalities to invest in similar infrastructure.

The multi-stakeholder investment mechanism used in Shenzhen is more replicable elsewhere. (Chan et al., 2018; UNESCAP, 2021). The initiatives taken by Shenzhen are replicable in other densely populated coastal cities globally, but particularly in Southern China given climate and vegetation (Lancia et al., 2020). The Pearl Delta is a much larger urban space with multiple coastal cities such as Dongguan and HongKong who can be immediate beneficiaries of rain gardens used in Shenzhen due to identical climate and geographic conditions.

Despite private-public partnerships existing to fund rain gardens, multi-stakeholder engagement could be strengthened. There is a lack of public participation in decision making, meaning this is a relatively top-down solution. However, there is space for bottom-up collaboration which requires policy support to nudge the municipality in that direction (Wang et al., 2022)

An estimated US$ 302 billion will be required to transform cities across China, so a predominantly public sector push would be insufficient. Nearly US$ 1 trillion is required by 2030. There is a need for greater participation of civil society organisations to supplement the public sector investments to increase the pace of implementation as well as reduce the costs of maintenance and construction (Luo, 2018).

There is a need for increased domestic research to design better rain-gardens to maximise the effectiveness of land-use through spatial planning. Chinese R&D in rain gardens is relatively recent and publications are increasing annually comparing a variety of possible solutions and innovations (Cilliers et al., 2021). There has been a previous use of outdated simulation methods to plan and design Sponge City interventions. Systems need to update and partnership with private sector technical expertise is required. Better methods have shown that above-ground water storage is crucial to ensure the success of rain-gardens in flood-plains and reclaimed land (Lancia et al., 2020; Cilliers et al., 2021)

In general, Spong City programmes were more likely to be supported by better educated and more affluent individuals. Hence a whole of society integration is needed for better implementation. This could be achieved through the use of pilot sites to demonstrate the value of rain gardens to the public, especially the more vulnerable eldelry and poorer populations as well as better advertisement and education about the Sponge City Programme (Cilliers et al., 2021).

Overall, a key feature of rain gardens and the associated green and grey infrastructure proposed as part of the Sponge City Programme is its potential to aid in the recovery process. Given that the policy originated from a paradigm of making Chinese cities more resilient to pluvial flooding after a series of devastating floods, especially in Beijing, it could be seen as a recovery process (Luo, 2018; UCF, n.d.). However, these infrastructure have a common role in reducing the damages caused by flooding by slowing and controlling the flow of water while also capturing it and percolating it. Thus, they mitigate flood damage. In doing so, the reduced level of damage and milder impacts ensures it is easier for the urban area to recover and build back better more quickly. This feedback loop dynamic will be discussed later in the conclusions section.

SMS Early Warning System

Socio-technological Solution

Low cost accessible flash flood warning system

Prevention | Mitigation | Prepardness | Response | Recovery

Nepal Telecom: GSM Coverage in Nepal

Best-practice description

- Pilot in 2016 after MoU signed with Nepali telecom firms
- National Flood Forecast Centre monitors rivers and warns locals through SMS if flood level thresholds are crossed
- Free provision of SMS helps the spread of the message and evacuation coordination

Cost-effectiveness

- Cost of sending 100 bulk SMSs is US$ 0.21
- Use MoUs with private and social sector allowed for spread of responsibility and financial burdens
- Telemetry automation of flood gauges to improve flood warnings and forecast assurance

Feasibility

- Much lower cost of implementation given budgetary constraints
- Integration of hydrological and meteorological functions under same agency makes for efficient warning generation

Equity

- Mobile services and SMS are financially and physically accessible for rural Nepal
- Free SMS allows evacuations to be conducted by social sectors and local youth
- At least 1 member/household had a mobile phone compared to only 13% having Internet access

Challenges, Solutions & Scaling

- National system is unable to adapt to local needs, need for contextualisation of warnings
- Public is often unaware in certain areas about how to react to warning, education initiatives are required
- High levels of gender and regional inequalities in terms of information access

3. Preparedness

3.1 Socio-technological solution

3.1.1. Background and Relevance

Nepal is a land-locked country located between India and China on the Himalayan mountain range. Much of its territory is mountainous and lies along a fault line and has some of the highest peaks and largest glaciers worldwide. This makes Nepal one of the most disaster prone countries in the Asia-Pacific region. Nepal receives much of its rains through the monsoon like most of the Indian subcontinent. The annual Southwest monsoon begins in June and peaks in July and August bringing with it heavy spells of rain. The heavy rains lead to seasonal flooding along Nepal's valleys and low-lying Terai region. Mountain soils have a low capacity to retain water in their intergranular gaps. This means that during the monsoon season, they quickly reach their maximum holding capacity and thus excessive rainfall causes the formation of runoff. This run-off quickly travels downslope and accumulates in small rivulets and streams. The high volume of water and the narrow passage of water leads to a rapid overflow and over short periods of time a sharp rise in water levels along rivers and streams which are relatively densely settled. This leads to flash floods which have relatively short lead times with which preparedness and response measures can be coordinated. The flash floods' sheer force also loosens mountain soils and weakens soil structures due to erosion which also leads to fatal landslides. Overall, it is estimated that floods and the landslides associated with floods are the root cause for around 75% of all disaster related casualties in Nepal (Department of Hydrology [DHM], 2018)

In 2017, Nepal faced an unusually heavy monsoon which led to widespread flooding, especially in the Terai region. The Babai river basin located in Western Nepal flooded severely and caused widespread damage to housing and common infrastructure which heavily disrupted the livelihoods of the riverine communities settled in the valleys (Karki, 2017). Most of Nepal's 6,000 rivers, like the Babai river, flow southwards towards the Terai region and onwards to the flatter plains in India. Nepal's mountainous landscape means that the rivers in Nepal flow with a much higher velocity and this could have more severe impacts due to the ferocity of currents in a flash flood (Meechaiya et al., 2019). It was estimated that in 2017 alone, 1.7 million people, mostly from the Terai region were displaced and the disruption to local economic activities, impaired infrastructure and loss of lives led to a 3% loss in GDP (DHM, 2018). Climate change has had severe impacts on the intensity and erraticity of monsoons across the Indian subcontinent. The monsoons have become more intense exacerbating the risks of stormwater run-off, flash flooding and landslides. Furthermore, they have also become increasingly erratic, meaning that their predictability has declined. This further puts the Terai at the risk of sudden, unprecedented flash floods even among small rivulets which are less prone to flooding. This has led to a deterioration of Nepal's flood-risk levels (Bhandari et al., 2018).

3.1.2 Justification

Nepal is an emerging economy that remains predominantly rural and highly dependent on remittances from the Nepali diaspora in India. This leaves the Nepali government minimal financial and physical resources to implement a highly sophisticated and advanced flood or multi-hazard early warning systems as observed in Japan or Europe. Given the budget constraints faced by the government as well as having to confront multiple possibilities of allocating funds, the DHM does not have a substantially large budget. Within this meagre budget, the DHM has made use of simple technological interventions when private sector specialist software and annual licensing costs for high resolution information remains out of reach (DHM, 2018). Therefore, the utilisation of SMS and coordination with civil society stakeholders to empower at-risk rural populations and prepare them to emerge resilient from rising flood-risk is essential.

3.1.3. Best-practice Description

The DHM has multiple such gauges throughout Nepal. Some are directly maintained by the DHM and data generated by the gauge is automatically fed into the National Flood Forecasting Centre through telemetry transmission technology. These gauges are established along with technical support from Ncell and Nepal Telecom to form a nationwide network that can measure water levels and basic meteorological information. They are further supported by the NGO Practical Action in various sub-basins to assist with instalment and local information dissemination to residents of at-risk villages. However, not all gauges are monitored telemetrically, some continue to be manually monitored. In that case, a member of the local community is given an official title by the DHM and has the responsibility to monitor the manual gauges and report back to the DHM. Updates are given to the National Flood Forecast Centre [NFFC] associated with the DHM (DHM, 2018). The gauges which are automatically or manually measured have a key flood threshold level. When this is crossed, a warning is automatically sent to the NFFC or the local community water gauge reader will immediately report to the NFFC (Karki, 2017). Typically, the threshold is measured in terms of precipitation over a 3 hour period. The NFFC then integrates these streams of data and validates them to create a model that predicts the potential course of the fluvial flash flood, triggering SMS warning messages to be sent out to multiple key stakeholders in the relevant basin (DHM, 2018; Karki, 2017).

The SMS has expanded since 2015 to include more stakeholders as previously it was limited only to technical persons (DHM, 2018). Ground-level demand by at-risk villages, particularly in the Terai region led to a more publicly accessible SMS system being developed from the previous exclusive system (Practical Action, 2017). The DHM also followed up with a set of SOPs designed around the SMS notification system to better improve preparedness and evacuation (DHM, 2018; DHM, 2015).

To ensure accessibility to SMS by the general population, the Government of Nepal under the advice of the DHM and Practical Action signed a Memorandum of Understanding [MoU] with Nepal's largest telecommunications services providers Ncell and Nepal Telecom (Practical Action, 2017). The telecom firms provided free SMS early warning messages relayed from the NFFC and DHM as well general free SMS services in flood affected regions to ensure ease of coordination of preparedness and relief efforts. This system was first piloted in 2016. The water gauge set-up at the Chepand village was used to measure water levels in the Babai river. Immediately threshold levels were crossed after heavy precipitation and thus the government of Nepal sent out mass text-alerts prior to the arrival of the flash flood to alert at-risk communities to evacuate. The DHM had warned over 50,000 at-risk residents in the relevant river basins through SMS with sufficient lead time to take preparedness measures and evacuate, leading to lower than usual fatalities for a flood event of that intensity (Practical Action, 2017; Karki, 2017).

Local communities were able to better understand flood risks as levels of dangers. They also better comprehended warnings due to the increased outreach of the SMS system. Currently, the system covers only 8 polygons (regions) in Nepal and is undergoing expansion to cover 42 polygons to serve a larger population and area over time (International Centre for Integrated Mountain Development [ICIMOD], 2019).

3.2. General Evaluation

Nepal's SMS system allowed easy access and wide spread of its early warning saving many at-risk people from fatalities from increasingly severe flash flood events. It is also an affordable solution that is easy to implement for a government with minimal financial resources. However, coverage is still expanding and additional non-structural measures will be required to further the effectiveness of the system.

3.2.1. Cost-effectiveness

The provision of free SMS services allowed efficient evacuation and response in local flood-affected communities. In 2017, around 10 million (1 crore) SMS messages were sent over a span of 3 days in Nepal Telecom's network. In addition to the free SMS services, Nepal Telecom also sent 486,000 (4 lakhs 86 thousand) early warning flood alerts to affected areas in the Terai region under the direction of the DHM (Nepal Telecom, 2017). Reports from the ground demonstrated that this reduced fatalities as many youth actors were able to relay messages within their communities to catalyse the evacuation process. It also ensured no additional financial burdens were placed on the vulnerable populace for coordinating their own preparedness and response measures (Practical Action, 2017). The use of an M0U by the DHM was strategic in ensuring the mass availability of an accessible coordination technology to the residents of the Terai region while also not having to provide an additional fiscal push in that regard. However, even if the DHM or NFFC had to pay for the text services, it is highly affordable for the government departments. The cost of sending an SMS is NPR 1.00 (US$ 0.008) for the Nepal Telecom Network (Nepal Telecommunications, n.d.). The cost for sending 100 bulk SMSs on the Ncell network was NPR 26 (US$ 0.21) or NPR 0.26 (US$ 0.0021) per SMS. This price is accessible for the DHM given its meagre budget.

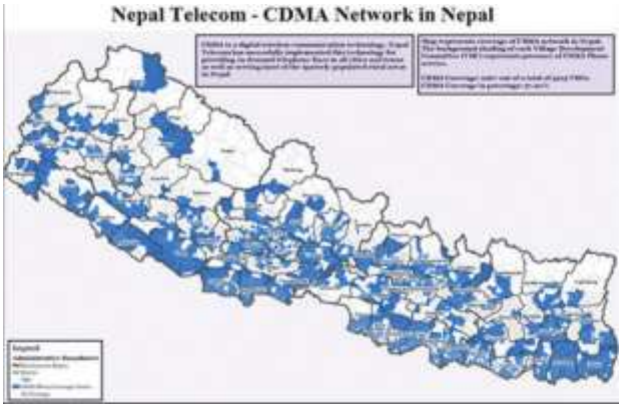
The cost of monitoring the water levels is also relatively low. In general the cost of maintaining a telemetry monitor for a period of one month was approximately US$ 8 which amounts to annual cost of US$ 96 (NPR 12,115) (DHM, 2018).

SMS technology is also accessible to the Nepali public, making it an effective tool to get in touch with the largest number of people quickly. Given Nepal's low

GDP/capita of US$ 1,115 in 2020 and the low cost of SMS and other telecommunications services in Nepal, the number of mobile phone subscriptions is 131% of Nepal's population as of 2020, thus a large proportion of the population reachable through SMS services (World Bank, 2020a; World Bank, 2020b).

Overall, it is estimated that the cost-benefit ratio of a flood early warning system is 1:11. This means that on average the benefits of an early warning system to improve preparedness and response measures would be 11 times that of the cost of setting it up. Using an accessible early warning system for the public makes it all the more beneficial as a large proportion of the population becomes reachable (DHM, 2018)

[***Figure 15:*** *Coverage of Global Mobile COmmunication System Infrastructure in Nepal (DHM, 2018)*]



[***Figure 16:*** *Nepal Telecom Network COverage Map (DHM, 2018)*]

3.2.2. Feasibility

Using MoUs to coordinate with local civil society organisations, the DHM is able to bridge the gap between its national scope of action and local contextualisation and knowledge. This ensured that the DHM, which always had to remain focussed on the bigger picture and long-term trends was able to do so while local civil society was given a more empowered position with which to operate with it, ensuring a reduced burden on the governmental first responder services.The DHM had roped in NGOs and the private sector to assist with disseminating messages as part of Nepal's early warning system. By spreading the responsibility across multiple stakeholders, the system is easier to implement and is more sustainable as the DHM's more centralised position made it less capable of maintaining databases of contacts at the local level. The strategic outsourcing of some of the manpower investment in early warning systems ensured that the system could be maintained by the government without straining its already tight budget position (DHM, 2018; Practical Action, 2017).

Structurally speaking, the DHM has two key functions as an organisation. It monitors and researches Nepal's hydrology as well as meteorology. This has made the agency primed for spearheading early warning systems in Nepal as it is able to integrate and work with related and diverse data sets which would usually be under the purview of different agencies. This eases coordination within the DHM at the national level. Disaster Risk Reduction and Management Act of 2017 mandates the Government of Nepal to upgrade its early-warning system through research and development at a national level. This is possible for the DHM to undertake which it has already done and continues to invest in (DHM, 2018, ICIMOD, 2019). Article 50 in the Nepali Constitution mandates the decentralisation of power to the local level governments to manage early warning systems and invest in flood preparedness that is suited to the local scenario. This allows for better contextualisation of systems and adaptive measures. DHM regional offices have previously assisted in sending out warning messages generated from the national DHM office and the NFFC to local and subnational actors as they have a better localised database of contacts within villages and municipalities as well as within NGOs such as Practical Action (Meechaiya, 2019; DHM, 2018).

Finally, Nepal's telecom infrastructure continues to expand rapidly becoming more accessible for remote and rural populations. It is also relatively resilient. When heavy rains interrupted telecom networks in 2017, around 91% of the coverage was restored within a span of a few days allowing for rapid relaying of messages (ICIMOD, 2019; Nepali Telecom, 2017).

3.2.3. Equity

In 2017, the text messages were utilised to coordinate between local NGOs to evacuate 4,700 vulnerable people from villages (Karki, 2017). Many villagers were successfully evacuated by boat or foot given the relatively short lead times associated with flash floods.

[**Figure 17:** *Boat Evacuation Triggered by EWS in Jhapa, Nepal (Bhandari et al., 2018)*]

Field visits indicate that at least one member per household has access to a mobile phone, but very few have internet access or smartphones. SMS allows for better dissemination of warnings than the DHM website due to its greater penetration among the population, especially in rural areas. While they are natively Bhojpuri speakers, people in the flood-risk areas of the Terai region also understand Nepali warnings and were able to comprehend and act upon them. Use of vernacular languages such as Nepali over English allowed better preparedness due to higher levels of comprehension (DHM, 2018).

74% of the population has access to mobile phones compared to 39% for radio and 13% for internet. New provisions under the DRRM Act allows NGOs to play a greater role in flood forecasting and preparedness activities at a local level. This can better integrate the more vulnerable sections into the population as NGOs often have the highest resolution of knowledge for local circumstances as well as local social and power dynamics. This could ensure that vulnerable and illiterate people can still be reached and warned in time for evacuation (Meechaiya, 2019).

3.3. Barriers, Expectations and Solutions

Despite the relative success of the measure, many key challenges exist. The most vulnerable often do not understand the gravity of flood alerts and delay their own evacuation. Coordination with local authorities and civil society organisations is required to ensure complete evacuation. This leads to irresponsible behaviour such as reluctance to evacuate or even heading closer to flood waters. Furthermore, poorer areas are unable to respond to SMS as more people tend to be illiterate in these regions and written warnings cannot be easily understood (Karki, 2017; Bhandari et al, 2018)

Awareness of text alerts has been low initially, but has been lately improving due to local efforts to inform vulnerable populations (Karki, 2017). However, better training and education would be required to ensure at-risk populations better understand how to comprehend a message and how to act upon it appropriately to aid evacuation such as immediately safeguarding important documents in a waterproof bag prior to evacuation.

The DHM is a national organisation that lacks high resolution knowledge of the local context. A national flood-warning system, while useful, may not be able to adjust warnings to local contexts. National mandates have already begun to push the public sector towards localised early warning and preparedness measures. Local level governments lack resources for flood forecasting, forcing the NFFC and its services to remain in the national domain. SOPs need to be developed at the local level although they exist for national level (Meechaiya, 2019; DHM, 2018)

Warning systems for flash floods need to be more efficient as they are less predictable than fluvial floods. In some basins the lead time is as low as 15 minutes (Bagmati river at Sundarijal) while in others it is as high as 22 hours (Kamali at Chisapani). Water levels in Chepang very quickly breached warning and danger levels indicating that flash flood response and preparedness is necessary (DHM, 2018; Bhandari et al., 2018)

Nepal's mountainous terrain leads to service gaps despite the relatively wide coverage provided by Ncell and Nepal Telecom (DHM, 2018). However, the telecom network in Nepal is undergoing expansion and upgradation (ICIMOD, 2019).

Funding of monitor maintenance needs to be decided. Roping in local stakeholders such as villagers, NGOs and local levels of government may help further reduce the costs of monitoring (DHM, 2018)

There is a major gender gap in Nepali flood warning access. While 77% of men received early warnings, only 33% of women did. Additionally, higher NGO presence in Western Nepal means that municipalities in the west are more likely to have functional evacuation plans compared to the East. Thus gender and regional inequalities need to be addressed to ensure this best-practice can be further improved and become accessible to all Nepalis (Meechaiya, 2019).

As noted in the above discussions, the SMS warning system served multiple stages. While the concept was predominantly developed as a way to warn and prepare vulnerable populations to quickly evacuate before a flash flood, the provision of free SMS facilitated coordination of response efforts and relief efforts of the (temporarily) displaced population. It also prompted faster recovery due to fewer fatalities. These feedback loops will be further discussed in the conclusions section.

Small Unmanned Aerial Vehicle

Socio-technological Solution

Aerial surveillance of high resolution to inform flood response

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description

- Fort Bend County conducted surveillance of city during severe floods in 2016
- SUAVs are launched in open spaces and then capture a variety of recorded data in 15 minute flight
- Data is then processed in a mobile laboratory to generate useful insights and predictive models

Cost-effectiveness

- Cost of an SUAV is US$ 1,000 to US$3,500 which is cheaper than surveillance from satellites or the military
- The resultant data and elevation models were of high quality and comparable to LiDAR
- Realtime data measurements

Feasibility

- Requires trained technical experts to operate SUAV as well as process the resultant data into useful output
- Data transfer to mobile laboratory must be done via storage drives due to high volume
- 30 minute battery life is more than sufficient for each surveillance round

Equity

- SUAV footage was released on Youtube for ease of access for public
- Local knowledge experts were able to bridge the gap between technical experts and residents

Challenges, Solutions & Scaling

- Technical and time limitations in processing data, challenging for flash floods
- Increased research and development of machine learning and AI capabilities to reduce manpower use
- Need for technical expertise, service level agreements may help streamline response management in the future

4. Response

4.1 Socio-technological solution

4.1.1. Background and Relevance

Fort Bend is one of the largest urban areas in Texas and is a satellite town to Houston. It has a blend of dense urban, suburban and rural areas. It currently has an estimated population of 822,779 people as of 2020 (Murphy et al., 2016; United States Census Bureau [USCB], 2020). Fort Bend was hit by two floods in April 2016 and May 2016. The flood in April had the fourth highest water level on record while the one that occurred in May had the highest water level on record, exceeding the previous one by four feet. Both floods were thus declared as natural disasters by the President. Fort Bend's location close to rivers has made it particularly vulnerable to fluvial flooding, in addition to risk of pluvial flooding from rainfall caused by hurricanes which are common in the Texas region. The Fort Bend Office of Emergency Management (FBCOEM) made use of Small Unmanned Aerial Vehicles (SUAV) to assess damage and amend response plans accordingly (Murphy et al., 2016).

4.1.2 Justification

First responders to a flood could potentially benefit from aerial images of the flood site. This allows them to plan evacuation routes as well as predict the possibility of further damage and prioritise actions accordingly. The results can improve the efficiency of rescue missions and overall response to the flood by allowing first responders to better visualise and understand the risks present on the field (Murphy et al., 2016). In general, an SUAV can be used for 7 types of missions. These include strategic situational awareness, examination of buildings, water search and rescue, ground search and rescue, flood damage assessment, assessment of transport infrastructure and to deliver key materials. These missions all play a central role in gathering reconnaissance of the flood situation (Murphy, 2019). Unlike satellite imagery, SUAVs can easily navigate flood regions and take higher resolution data with a possibility to revisit the site for multiple data inputs. This is because SUAVs (pictured in figure 18) can fly closer to residential areas and flood sites compared to conventional manned aircraft and helicopters. They can also fly below cloud cover, offering a higher resolution than satellites which are more difficult to control given how far they orbit the Earth. Thus SUAVs have seen increased adaptation as a tool to inform response in emergency services globally, but especially in the United States (Hashemi-Beni et al., 2021).

[***Figure 18:*** *Unmanned Aerial Vehicles used by Emergency Office in Fort Bend County (Murphy, 2019)*]

4.1.3. Best-practice Description

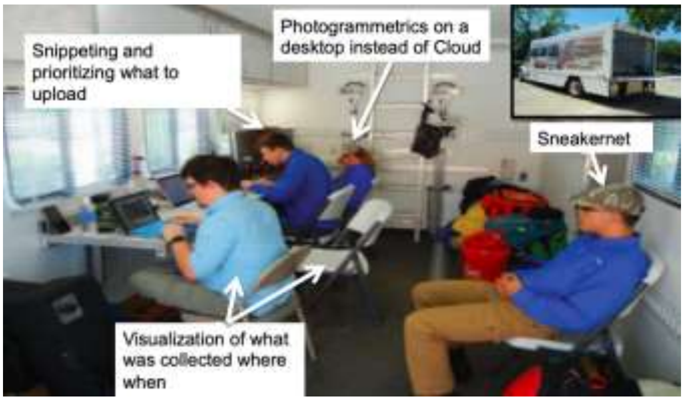
The FBCOEM was able to coordinate with a non-profit Centre for Robot Assisted Search and Rescue (CRASAR) who provided the SUAVs. Technical experts typically plan to measure data from strategic spots across the county to optimise the coverage of the county area as well as to prioritise the most at-risk regions. They then drove by car/jeep from location to location to conduct aerial surveys and returned to the Emergency Management Centre to transfer the data into computer systems. This process tool around 45 minutes on average given the poorer road conditions during flood events (Murphy et al., 2016)

On average the set up time for the SUAV at each site was less than 15 minutes provided there were suitable landing spaces and distances from aerial obstructions around the launch area. The SUAVs were flown around 118 metres (390 feet) in height to avoid exceeding the mandated legal limit of 122 metres (400 feet) set up by the Federal Aviation Agency. The legal limit is in place to ensure that SUAVs do not fly into commercial or defence airspace where they might get damaged by larger aircraft or interfere with parallel surveillance or rescue operations. Each flight operated within a 800 metre (0.5 mile) radius from the launch site and also within the height restriction to ensure its continued visibility to the operator. The data was analysed in a RESPOND-R mobile laboratory using multiple softwares including CartoFusion and AgiSoft. The RESPOND-R mobile laboratory can be moved from one location to another to better coordinate emergency responses if a site had to be moved. In 2016, all data processing occurred within the premises of the FBCOEM (Murphy et al., 2016).

An SUAV can produce ephemeral (non-recorded) low resolution video live to the operator. This data was used by the operators to judge if the actual flooding has largely followed that of the model or if there have been any major discrepancies. This comparison can be insightful in terms of finetuning predictive models that could warn communities that may be at future risk of flooding or identify areas to pre-emptively evacuate. Additionally, it is able to record higher resolution video as well as high resolution photographs which contain geo-tags that indicate precise location. This recorded information is stored in a Secure Digital (SD) card inside the SUAV. Data was also derived from the recorded data using third-party softwares. SituMap is a land-use planning and visualisation tool from CartoFusion which is able to display collated data. This software was used to produce two maps to inform decision making. Firstly a map was made indicating the locations of all the images taken. The second interactive map included data such as the area's digital elevation model (DEM) and normal satellite photographs to current (flood) photographs. It further permitted the data analyst to measure distances and areas as seen in the below figure 19 (Murphy et al., 2016).

[***Figure 19:*** *Images from Unmanned Aerial Vehicles in Fort Bend County, Texas (Murphy et al., 2016)*]

The Exchangeable Image File Format (EXIF) system was used to tag the latitude and longitude of the photograph thereby storing geographic information. These EXIF tags were used to automatically position the image taken by the SUAV with the base images of the same area/region to generate a before and after flood map of a location for the sake of comparison. The above data is complex for an average operator to process. Thus there were dedicated data managers on the response team. The data manager plays a key role by backing up recorded data, saving it and labelling it and finally recognizing high value data points and ensuring its ease of access. Furthermore, they also collate data from various SUAV flights and process it using third party softwares to produce useful maps and output for the FBCOEM. Some footage and outputs were made available to the public to keep them informed on platforms such as YouTube (Murphy et al., 2016; FBCOEM, 2016).



[***Figure 20:*** *Inside and Outside of RESPOND-R Mobile Laboratory (Murphy et al., 2016)*]

4.2. General Evaluation

SUAVs are a potentially easy to access, cost-effective and feasible to implement solution to generate high quality and real time information of the status of floods to amend and adjust emergency response. The data gathered can also be published in a format that is easy to comprehend for the everyday citizen. However, there are multiple technical limitations for this technology. Nevertheless, continued research and development in this technology only makes investing in it more compelling as an attractive and functional tool for flood response.

4.2.1. Cost-effectiveness

The SUAVs were able to assess the extent of the flood and measure possible flood heights as gauges and predictions were giving erroneous readings. Thus, the flood heights which are also known as crests could be more accurately measured in real-time. The SUAVs were also able to reconcile actual observations with other predictive models to improve modelling to better predict the future extent of the flood and provide useful data for the FBCOEM to plan responses (Murphy et al., 2016).

With respect to the financial investments required, the cost of the SUAV as well as any licensed third-party softwares need to be taken into account. The estimated cost of a SUAV is US$ 1,000 to US$ 3,500 depending on the data output it produces. Those which produce low resolution images are cheaper than those which can produce higher resolution video output. However, in 2016, the SUAVs were made available by CRASAR on a temporary basis and no rent was paid. However, in the long-run it may pay-off to invest in a dedicated SUAV to serve the county. A SituMap licence costs US$ 1,000 and is able to process data in 1 hour's time. This could further contribute to the county's response to flooding. These costs are relatively meagre when taking into account the county's large population and thus potentially large tax base (Murphy et al., 2016; USCB, 2020)

In general the elevation models generated by SUAVs are comparable to those generated by satellites or LiDAR technology and could be applied for fluvial flooding such as the Fort Bend case. They also are able to fly below cloud cover meaning that they are able to generate decent resolution data in comparison to satellite image. This means that for the above cost investment, the output of SUAVs are often of high quality that can be used to inform local response efforts properly (Antoine et al., 2020).

4.2.2. Feasibility

The drones need technical experts from CRASAR to be operated. However, as the operators have less local knowledge, collaboration with the FBCOEM and the Fort Bend County Drainage District were required to ensure a proper coverage of the surveillance. Thus at least three people were required for the operation of any given SUAV flight mission. This is because at any moment, one person was required to fly the SUAV, a second individual was to monitor the flight to ensure all safety protocols were followed and is a federally mandated requirement, and finally a local expert was able to contextualise the surveyed area. It is possible that in particularly lean times where personnel available are limited, it is possible to conduct this in pairs instead (Murphy et al., 2016; Murphy, 2019). On top of the technical experts who operated the SUAVs, the large volume of data generated required full-time specialised data management personnel to be present to enter the rapid processing and visualisation of data output (Murphy et al., 2016).

Given the flight radius required was 800 metres (0.5 miles), the SUAVs usually had more than sufficient battery capacity to last the 15 minute flight so they can continue to operate if a longer flight time is needed. The battery also can be charged by a car inverter rather than a special generator making it easy to transport and charge. The average battery life of an SUAV is estimated to be around 30 minutes, which is more than sufficient time to make a proper surveillance of the prescribed radius. Furthermore, the SUAV was able to charge quickly while it was being transported from one launch location to another (Murphy et al., 2016; Murphy, 2019; Hashemi-Beni et al., 2021).

4.2.3. Equity

The SUAV footage proved very useful in bridging the differences between the technically oriented responders and the everyday citizens of Fort Bend. The use of before and after flooding images were useful in convincing and warning the most vulnerable communities which were not yet affected by the flooding to evacuate and provide a live and realistic visual of the possible damage and risks they may face (Murphy et al., 2016).

The upload of SUAV footage on Youtube ensured it was accessible for those who were unable to help their at-risk relatives. Youtube is a widely used platform in the United States and more straightforward to access for a larger age group given the higher levels of internet penetration in the United States. Many areas which were out of risk were also pointed out to reassure the public of the progression of the flood and avoid panic-induced behaviour which would divert scarce emergency response resources. This ensured that the FBCOEM had to handle fewer unnecessary preemptive calls and focus their rescue missions on those facing higher risks, greatly improving the flood response by using a risk-based paradigm (Murphy et al., 2016; FBCOEM, 2016).

Local experts were able to bridge the gap between everyday citizens and property owners and technical teams. Very often teams were approached by local residents with concerns about approaching floods during flight operations. Ensuring the easy understanding of the situation allows the resident to make better decisions privately with a relatively good knowledge of the situation. While a technical expert would be unable to explain the implications of the flood level or progression to a resident, a local expert form the FBCOEM or Drainage District who is familiar with the neighbourhood would easily do so (Murphy et al, 2016).

SUAVs are more affordable, accessible and transmit data at a higher resolution than satellite imagery which allows for better response and a solution that is within reach for many local or regional emergency authorities. Given the smaller scales and budgets of local level offices, such solutions are much more within reach than larger interventions as conducted by national organisations such as the military (Murphy, 2019).

4.3. Barriers, Expectations and Solutions

Despite the improved response to the flood, there were some key challenges identified within this best-practice. Firstly, each team had to drive 58 miles per day of survey indicating a large amount of time was spent in driving from location to location than to collect useful data (Murphy et al., 2016)

The EXIF tags occasionally had slight inaccuracies as the camera may not have always been positioned straight down and only reflects the SUAVs position. However, these could be manually adjusted. However, given the short time frame, the map was of reasonable accuracy to draw conclusions and to use after this manual adjustment process. On average it takes around one minute to rectify and manually adjust inaccurate images. However, if unusually large volumes of data are required, manual adjustment may be time consuming in a shorter response time frame (Murphy et al., 2016).

Using operators who double as data analysts inhibited the performance of the SUAV as the data output was too voluminous to be processed in time to produce useful output. A dedicated data team had to be set up. However, from a preparation point of view, there is no guarantee that technically proficient volunteers will be available at all times. Therefore, the use of service level agreements with NGOs, private firms and other organisations such as CRASAR to ensure the availability of a pool of technically proficient volunteers for data management and processing. Additionally, machine learning could partially automate and reduce the labour required for image data processing which reduces the demand for additional manpower required to run these operations/missions (Murphy et al., 2016; Kremers, 2022; Munawar et al., 2021).

Large data volume makes data transfer through cell networks unviable. Physical transfer through SD cards and thumb drives was required, which took anywhere between 2 to 6 hours. This presents a significant delay in data processing and output production. This is particularly problematic for less predictable floods such as flash flooding where the lead time frame is short giving very little time to process data before it becomes potentially irrelevant to the status quo (Murphy et al., 2016).

SUAVs also are currently unable to generate useful data to assess damage to housing and property, especially in areas with a high green cover. This represents a key gap in information that would be of great utility to first responders. However there have been new AI softwares in development which are able to help with detecting edges of water inundation which could make damage assessment more feasible and accurate. This is further possible by the use of landmarks to assess flood levels and to estimate damage better. Research in these aspects of SUAV technology continues currently (Murphy et al., 2016; Munawar et al., 2021).

[***Figure 21:*** *Standard launch site for SUAVs (Murphy et al., 2016)*]

Launch sites required relatively open spaces without too many trees or overhead cables. This was difficult to find in the older and more densely built neighbourhoods. A good example of such an ideal launch site is depicted in figure 21. This is a major issue faced by fixed wing SUAVs which resemble aeroplanes in terms of build. However, this issue can be partially overcome by using a rotor-winged SUAV which resembles a helicopter and requires less space for take-off and landing. However, rotor-winged SUAVs do have poorer battery performances and cover a smaller area at a higher resolution. The trade-off must be considered prior to implementation depending on the area that needs to be surveyed and the nature of that area(Murphy et al., 2016; Murphy, 2019; Hashemi-Beni et al., 2021).

There is potential to apply this technology in a preventative or preparedness manner by regularly survey rapidly developing regions or making surveys prior to flooding season to then follow-up with preventative interventions. The predictive flood modelling can be improved by integrating SUAV data from previous flooding events with an AI model (Murphy, 2019; Munawar et al., 2021).

It could also assist with the recovery process to survey damages and make priority oriented decisions for effective rebuilding of the damaged areas. In the long-run, machine learning could be used to improve the quality of images to detect morphological changes caused by floods, its possible consequences and thus guide the redevelopment of the region. However machine learning automation still requires up to 13 hours of preprocessing of image data. However, they have an 87.3% accuracy in the most recent tests indicate promising developments (Murphy, 2019; Munawar et al., 2021; Antoine et al., 2020).

Despite the above discussions and developments, the most recent floods in Fort Bend saw a nearly identical response with mostly the same best-practices used. However, the newest development in this case was the use of the Hanger360 application to stitch image data into panoramic visuals and share it rapidly among the public as visuals which aided response (CRASAR, 2019).

Overall, the rapid response towards a flood ensures the recovery can also occur at an accelerated pace. Despite the large scale and economic destruction caused by the floods in Fort Bend, very few casualties occurred and the region has continued to see rapid growth and development. This feedback loop will be further discussed in the conclusions section.

Bioswales

Nature-technological Solution

Use of natural drainage systems for pluvial flood

Prevention → Mitigation → Prepardness → Response → Recovery

Best-practice description

- Climate adaptation initiative for low income social housing estates in Fulham & Hammersmith Council
- Swales were built to improve conveyance and drainage of stormwater
- Swales were tested for structural integrity and were carefully planned for optimal drianage

Cost-effectiveness

- Installed swales could handle 40mm rainfall events which are unusually voluminous events
- Up to 87% reduction in mean run-off volume generation for standard rainfall events
- Along with other green infrastructure, annual costs are €21,700 for large number of beneficiaries

Feasibility

- Requires some level of planning to retrofit into built spaces, most potential in medium density estates
- Relatively low maintenance requirements; drain clearing and vegetation trimming
- Could potentially mimic natural hydrological patterns

Equity

- Used in social housing, allowing most vulnerable to be able to adapt to changing climate
- Generation of local economy and integration of most vulnerable stakeholders to take ownership

Challenges, Solutions & Scaling

- Difficulties in retrofitting in very high density settlements
- Difficulty in evaluating economic benefits using traditional economic models
- Parallel feedback loops where recovery and investment in swales improved future capacity to mitigate floods

5. Recovery

5.1 Nature-technological solution

5.1.1. Background and Relevance

London's population is growing from 8.6 million currently in 2020 to 11 million by 2050, a record high absolute increase in population in its history. Summer rainfall volumes have decreased by 6% by 2020 and are expected to decrease by a further 18% by 2050 leading to a drier climate with more erratic rainfall. Conversely, the intensity of storms in London is expected to increase between 2020 and 2050. To further explain that while overall precipitation declines, the increased occurrence of storms places London in greater risk of pluvial flooding in 2050. To elucidate, London's climate is becoming drier, but more erratic putting at an increased risk of flash floods (Greater London Authority [GLA], 2015).

Around 20% of London's land area lies in the Thames flood plain which is a relatively flat and low-lying region prone to fluvial floods. However, it is well protected by traditional engineered solutions to prevent/mitigate fluvial flooding (GLA, 2015). The ancient Vicotrian drainage system however does not have the capacity to drain stormwater and sewage due to wear and tear over the centuries thereby increasing the risk of pluvial flooding and sewer overflows all over London. This is worsened by the higher amount of impermeable surfaces in London which delay and prevent drainage of excessive rainwater into natural water bodies or percolation in the ground water table. Furthermore, increasing maintenance costs for drainage and labour has led to deteriorating conditions and performance of the city's drainage infrastructure, further increasing the vulnerabilities of urban areas to flooding. The lack of water sensitive development interrupts natural cycles of flooding as well as removing natural water storage capacity which was part of London's hydrology, which would have helped to regulate flooding better (GLA, 2015; Potter & Vilcan, 2020; Green et al., 2021).

The situation looks even more bleak as London continues to lose green cover each year. The estimated loss is around 875 acres annually (Li et al., 2020; Royal Parks, n.d.). This reduces the amount of land that is able to drain excess stormwater, and thus exacerbates the aforementioned risk of pluvial flooding as green spaces gradually give way to housing. Inundation in cities increases the risk of the spread of water-borne diseases and interferes with emergency service provision leading to a higher loss of life and poorer health and economic outcomes (Green et al., 2021).

5.1.2 Justification

Green infrastructure has rarely been implemented as an integral part of the everyday urban-scape in the United Kingdom, as most agencies have traditionally operated in a paradigm where importance and emphasis was placed on grey structural engineered solutions to combat flood-risks. Thus, London could use this to its advantage to better adapt to climate change and flooding while remaining a greener and liveable city (GLA, 2015). With an increased emphasis placed on building back better and engaging multiple local stakeholders by the Sendai Framework of 2015, green infrastructure can allow cities to adapt to changing climate patterns to become more resilient to future flood-risks while delivering multiple other benefits including economic, psychosocial and ecological positive externalities. Thus, small scale green infrastructure that can alleviate local level pluvial flooding would be of great utility in securing London's future as a flood resilience and water sensitive city (UNDRR, 2015; Green et al., 2021).

5.1.3. Best-practice Description

Swales are broader, shallow channels which can be used to convey excessive rain water to a waterbody for storage or be used to catalyse the infiltration process of water into the groundwater table (SusDrain, n.d.). The sides of these channels are slope inwards to encourage water to drain into the swale rather than flow to other areas and have flat bottoms which facilitate the conveyance of higher volumes of water. They are also relatively compact compared to other forms of green infrastructure such as rain gardens (Transport for London [TfL], 2016).

[***Figure 22:*** *Conveyance swale system for rapid drainage (Connop et al., 2016)*]

Swales can be easily integrated into buildings and built-up land areas due to their compact design. Swales have been used in Queen Elizabeth Olympic Park to improve water drainage as well as storage after the land was gradually converted from built-up spaces to host the Olympics to a green space that functions as a natural drain and recreational space. They have also been previously implemented in the East Village to better handle storm-water run-off generated from the built-up land in the area (GLA, 2015).

[***Figure 23:*** *Roof pipe draining into a conveyance swale (Connop et al., 2016)*]

Swales installed were easily able to handle a 37.2mm rain event where the peak rainfall intensity was 188mm/hour. No pooling was visible indicating the swale's ability to drain and percolate water into the ground or convey it to a water storage body. Rooftop drainage systems were connected to the swale to hasten drainage as seen in figure 23. A one in a hundred year event would have led to 40mm of rain in a matter of an hour (Connop et al., 2016). In urban areas such as London, high population density makes retrofitting swales rather higher in cost. Currently, poor economic growth has reduced financing for essential utilities meaning that investing a swale has a higher opportunity cost (Li et al., 2018).

[***Figure 24:*** *One in hundred year precipitation testing on local swale (Connop et al., 2016)*]

[***Figure 25:*** *Swale in higher density neighbourhood (Connop et al., 2016)*]

[***Figure 26:*** *Swale in medium density neighbourhood in Fullham & Hammersmith Council (Connop et al., 2016)*]

However, they have been previously implemented successfully. Swale overflow designs were used to control overflow of water when the swale was at capacity. If a swale reaches full capacity, the overflow chamber releases water into standard drainage infrastructure.Swales are able to be tested through the release of water into the swale. Over 10,000 litres of water were released into the swale to test for absorption/conveyance capacity. No overflow occurred into the overflow chamber. These designs were used to construct swales in low-income housing estates in London in the Fulham & hammersmith Council (Connop et al., 2016).

5.2. General Evaluation

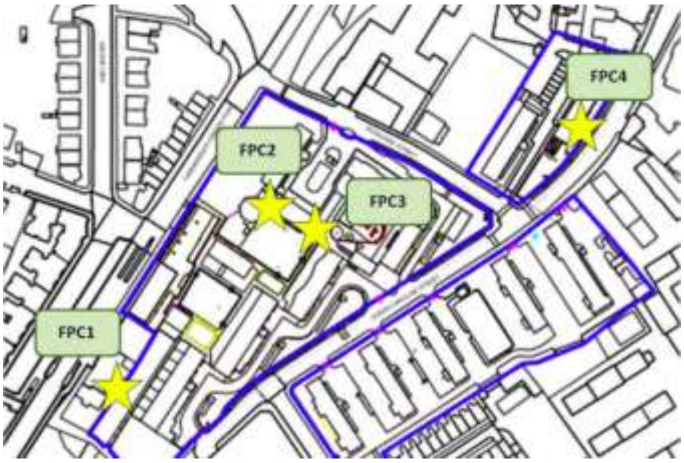
Swales are usually implementable at a mesoscale solution for flood-risk management and are a moderate to highly effective infrastructure depending on local contexts and implementation (Green et al., 2021).

5.2.1. Cost-effectiveness

Swales have lower capital costs and are relatively easy to retrofit into medium density areas without major and costly engineered interventions. Relatively low maintenance is required to keep a swale functional. These maintenance requirements such as clearing blockage sor trimming vegetation growth can be incorporated with existing maintenance by the public sector of common spaces (SusDrain, n.d.).

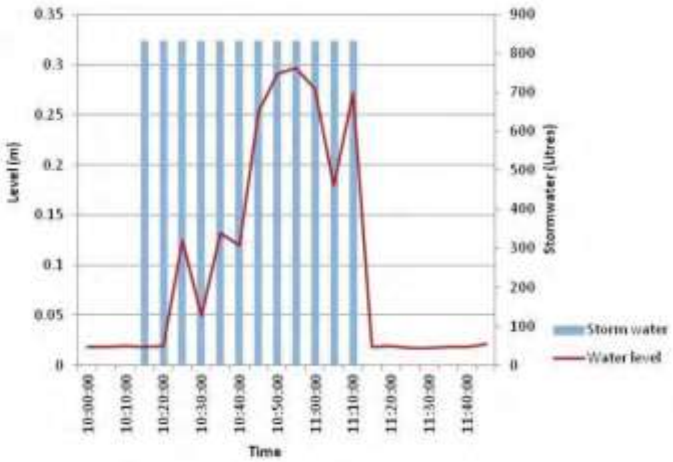
Overall, a well designed swale can reduce the mean volume of run-off from a rainfall event by upto 87%. In addition to that, the swale can also reduce the peak (maximum) run-off volume of stormwater from between 27% to 100% depending on local contexts and design constraints (Fairbrass et al., 2018).

The overall cost of implementing swales and other green drainage solutions for two social housing estates in the Fulham & Hammersmith council was €434,000. These investments lead to only light engineering works and retrofitting of these solutions which successfully diverted 100% of the excessive stormwater diverted away from the overburdened drainage system, resulting in a total of 1,286,815 litres of water annually (Climate-ADAPT, 2016). Overall, 4,537 square metres of land was improved and 22 unemployed youth were trained to assist with maintenance of the infrastructure.This particular project is expected to last a minimum of 20 years although the actual lifespan is variable. On average, excluding maintenance costs, the annual investment would have been €21,700 for the estates, which is an affordable amount, especially if multiple funding sources are utilised to distribute the costs across diverse stakeholders. The overall social return on investment which includes the total economic, ecological and social benefits for each unit invested in green infrastructure such as swales was estimated to be 4.39 times the initial investment (Climate-ADAPT, 2016).



[***Figure 27:*** *Location of swales and camera points in Fulham & Hammersmith Council, Social Housing Estate (Connop et al., 2016)*]

Outside of application in housing estates, swales can linearly attenuate flooding and store or convey flood-waters. This makes it highly implementable along major road and rail networks and can be justified in terms of London's high disruption costs for public transport. Green spaces on the side of transport corridors can easily be repurposed as swales, reducing the cost of retrofitting them (TfL, 2016).



[***Figure 28:*** *Graph of Water Levels in Swale after Storm (Connop et al., 2016)*]

5.2.2. Feasibility

Swales are easier to retrofit into medium and low density regions. This is because there is often more space available, especially along footpaths and roads and also in the form of empty lots which could act as possible locations to construct a swale (SusDrain, n.d.).

Low maintenance includes occasionally clearing blockages, cutting excess vegetation as well as cleaning out sediments formed over time. These processes do not require highly technical or trained professionals, and are thus more affordable and feasible to arrange for. Hence, the lower maintenance costs may even be able to make up for higher initial investments in more vulnerable densely built regions (SusDrain, n.d.).

Sustainable Drainage Solutions (SuDS) is generally more feasible when considered as a fundamental part of a new development than when it is retrofitted, as natural hydrology of the land can inform planning decisions while in existing built-up land, the natural hydrology is already ignored. However, despite these challenges it is possible to retrofit swales (Potter & Vilcan, 2020). Time Lapse cameras are an easy way to monitor the swales in a somewhat centralised and coordinated manner to check their performance and intervene in advance to avoid higher maintenance costs. Swales that are retrofitted in housing can be designed to withstand a one in a hundred year severe rain event. This greatly improves the resilience of the surrounding area (Connop et al., 2016).

5.2.3. Equity

Swales have been previously used to create an affordable solution to climate adaptation in low-income social housing in the London borough of Fulham & Hammersmith as part of the EU Climate-Proofing Social Housing Landscapes scheme. The scheme aimed to make low-income housing in European cities more resilient to the changing climate patterns they face. The development and implementation of swales in the estate involved local people and the implementing authority even hired lower income residents as apprentices and interns thus making the swales and other green infrastructure a source of employment for some of the most economically vulnerable residents (CLimate-ADAPT, 2016).

Swales were used to combat pluvial flooding in the Queen Caroline Estate and the Cyril Thatcher, Eric MacDonald and Richard Knight houses in the Fulham & Hammersmith Council. The Department of House Estate Services worked with NGO Groundwork London to spearhead this project. The Department acted as the lead coordinator on behalf of the local council of Fulham & Hammersmith. Thus, the potential for swale implementation is best when both technical and non-technical stakeholders work together. The scheme coordinates with both residents and maintenance contractors to train them on maintenance and involve them to ensure the long-run sustainability of the project (Climate-ADAPT, 2016).

In a time period when London's climate and rainfall patterns are getting drier and more erratic, access to fresh, clean water is of significant concern. Investing in bioswales becomes a form of multiple value creation within just the water sector as on top of managing floods, they can filter out silt and some pollutants which can be captured or synthesised by vegetation and the soil in/around the swale. Access to the bioswales throughout the city will be easy given that it becomes a form of decentralised holistic water-management nature-based solution. This means that its costs are easier to justify than centralised underground drainage systems which are difficult to build and maintain in a densely built city and could potentially benefit people across areas of various income groups, especially those of a lower income (Haase, 2015).

5.3. Barriers, Expectations and Solutions

While swales are a potentially emulatable best-practice, there are some key barriers to implementation at a larger scale. Traditional business and economic metrics are not capable of measuring the complex benefits of green infrastructure. This makes justifying the cost of implementation challenging (GLA, 2015).

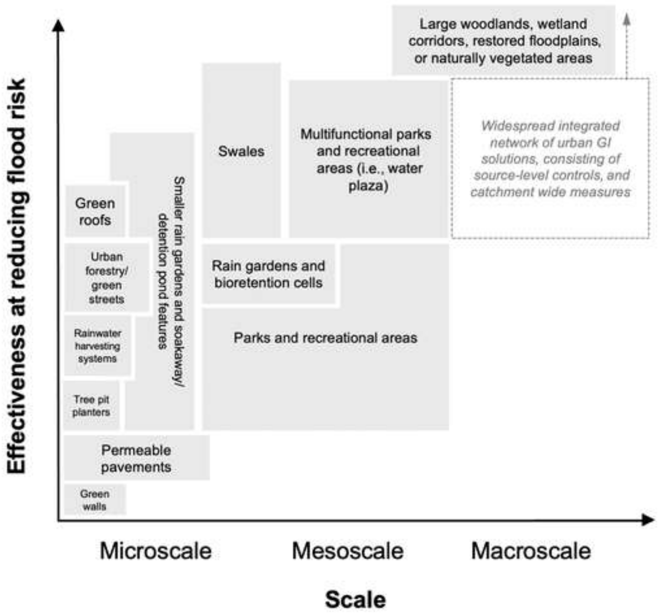
Even if budgetary concerns are answered, implementing green infrastructure projects for stormwater management and water quality involves multiple local authorities as it is best done at a catchment/basin level. This requires a higher level of coordination within the complex and large public sector agencies (GLA, 2015).

Transformation cannot only be driven by innovation and newer technology but also updated management practices and collaborative planning to account for uncertainties. Flood-management in England and London is largely centralised under the Environmental Agency. However, there are Lead Local Flood Authorities which handle flood-risk planning at a local level. Centralisation could be inefficient leading to less than optimal solutions at a local level. However, the Environmental Agency is increasingly working with the private and social sectors to combat this centralised, top-down approach. By using a locally oriented bottom-up approach innovation in management practices may allow for a smoother and more effective implementation of swales (Potter & Vilcan, 2020).

Lead Local Flood Authorities do provide advice to private developers, However, given the minimum requirements of the legislature, it is often ignored by developers due to the ease of achieving those standards. Further legislative tightening is required to rope in private developers by improving the minimum standards for buildings and green spaces. However, the National Planning Policy Framework strongly advocates the use of SuDS including swales throughout cities (Potter & Vilcan, 2020; Li et al., 2020).

At a local level, there is insufficient resources to maintain or monitor swales due to lower financial resources made available to local level governments who can best maintain and monitor swales (Potter & Vilcan, 2020). While local stakeholders are highly involved in the planning phase, this leads to confusion of responsibilities in maintenance in the UK. Therefore, a clear policy on how to implement maintenance systems for swales and other green infrastructure will be able to clarify the positions of the respective stakeholders. (Li et al., 2018).

Overall, it appears that the recovery process of building back better seen in social housing in London is highly replicable in other European cities. Interestingly, this investment in swales parallely increased the mitigative capabilities. Given that swales are able to better manage pluvial floods and encourage draining, they reduce the levels of inundation, thereby reducing the chances of damage caused by heavy rainfall (Climate-ADAPT, 2016; UCF., n.d.). This feedback loop will be further discussed in the conclusions section.



[***Figure 29:*** *Scale and Effectiveness Chart for Green Infrastructure (Green et al., 2021)*]

Public Best-Practices Discussion

Expectations:

Generally speaking, flood-risk management has traditionally fallen under the public domain. It continues to hold the most financial and technical resources, hence is the largest and most influential stakeholder. Most public sector organisations tend to have a broadly national focus. Given the large size and technical resources available to the sector, there is usually additional pressure to generate information on flood-risk solely by the public sector. To elucidate, the onus of generating data about flood risks largely falls onto the shoulders of technical wings of water management or disaster management agencies to collect geological and hydrological data to determine flood risks within a country's territory. However, the strong technical focus of these agencies mean that there may not always be sufficient resources to better understand vulnerabilities on a socio-economic scale which requires higher levels of local contextualisation (PUB01, 2022).

As discussed above, governments usually have specialised agencies which focus on disaster management, flood-risk management and/or water governance at a national and sometimes sub-national level. These agencies usually have technically trained members who are proficient as engineers or data analysts and can write detailed reports. Their skills and focus are thus geared towards the study and implementation of structural measures, particularly grey infrastructure such as dams or levees. However, they usually do not have sufficient capacity to contextualise the technical jargon to the populations at risk or the everyday citizen thus leading to a large information and communication gap. In general due to this, the public sector also faces pressure to educate the public through various means ranging from radio messages, television documentaries and through public education and broadcasting systems (PUB01, 2022).

The (usually) large size of the public sector relative to that of the social or private sector tends to lead to other stakeholders perceiving the public sector to have the majority stake in designing, funding, implementing and maintaining solutions to rising flood-risks in any country. Thus, there is an inclination to lean heavily on the public sector for support and benefits. To exemplify, many vulnerable communities seem to solely depend on the public sector to manage flood-risks and seldom (can) contribute to their resilience. Similarly, even private sector players tend to look towards the public sector for support, be it seed money to develop new technologies or funding infrastructural interventions (PUB01, 2022; PUB02, 2022; PAP01, 2022).

Public sectors throughout the globe also seem to have a culture of assuming that limiting the stakeholders involved in an infrastructural decision simplifies the decision making process. The logic behind this belief is that when there are fewer stakeholders, there would be fewer perspectives to consider. Typically the 'missing voices' are usually from the direct beneficiaries of such developments such as local residents who live in the affected region, small-scale civil society organisations and small and medium sized enterprises who are based in these regions. Given their less technically oriented knowledge, they are considered a less valuable source of input in any intervention. Given that collecting social and local knowledge involves a larger time investment, they are not given the same importance or substantial weightage in terms of contribution to decision making. This contributes to the continued technical-only orientation of the operation of many public agencies in a bid to save time and increase the pace of implementation. However, it is notable that agencies which operate on this approach have often failed in equitably improving flood resilience across all sections of society, or intervened in a sub-optimal manner. Thus, overall, there seems to be a resistance to integrating stakeholders due to these perceptions held by the public sector (PUB01, 2022; PAP02, 2022).

There is also a culture of investing in structural measures to prevent floods. "Essentially, they (the public sector) are trying to avoid the chance of floods entirely" (PUB01, 2022, 37:10). This therefore leads to a paradigm where physical and 'tangible' structural measures are given greater importance and priority over non-structural measures (PUB01, 2022; PAP01, 2022).

Barriers:

The sheer scale and available resources at the public sector's disposal may make it seem as a flexible driver of change. However, it remains rigid and inflexible compared to the private sector. Thus, changing approaches to flood risk management takes a larger time investment to execute given that more often than not, the public sector is locked into systems and legislations for long periods of time. This inflexibility is further buttressed by the expectations placed on the public sector by other actors and the overall culture of focussing on technical aspects of flood-management and investing solely or predominantly in grey structural measures (PUB01, 2022; PAP01, 2022, PUB03, 2022).

Adaptation is difficult when water governance is highly centralised, especially in geographically heterogeneous countries which simultaneously over burdens the sector. Firstly, centralised management of water governance (and flood management) is usually efficient at a localised level. It is also possible at a national level, however works best in smaller countries such as the Public Utilities Board in tiny Singapore (PUB, n.d.). However in larger countries such as Italy and India, centralised management is difficult due to high levels of geographic, geological and hydrological diversity in landscapes and natural water systems in these countries. This makes designing standardised policies and structural measures difficult as each river basin or region faces a different set of risks with possibly different factors which may improve or exacerbate the existing risks. This complication further slows down the public agency from restructuring or innovating as it is simply too large to strategically manage (PUB01, 2022; SOC01). Decentralisation is a difficult but viable process: “There are countries where decentralisation is more successful than in others. Power is not only state-based but state-managed…thus there is a real power play between the state (national) and the regions (subnational).” - (PUB01, 2022, 03:28). Notable success in decentralisation is visible in the Netherlands through the existence of water boards which operate on a regional level and are given sufficient power (PAP01, 2022).

Information available even in the technically competent public sector may be outdated due to high costs of gathering information. A top-down approach also overburdens the public sector to generate data. This also makes it more challenging for the government to adapt or try newer methods of research and information management as they remain locked-in with older methods and legislative provisions. This is particularly challenging when the socio-economic impacts of a measure must be increasingly considered when using a risk-based paradigm to manage floods (PUB01, 2022; PUB02, 2022).

There tends to be distrust between the public sector and potential private sector partners who often develop innovative technologies that could aid flood risk management. This also means that there is a culture of minimising stakeholder involvement which actually slows down the implementation of structural measures.

“This has proven unsuccessful many times … as seen in the city of Milan, the projects saw strong opposition from local municipalities and NGOs. Ultimately the project was never implemented and the money is still sitting on the table unused!” (PUB01, 2022, 23:31).

Furthermore, the culture of prevention focused risk management leads to high investment costs and they heavily depend on structural measures. This is also another effect of the expectations placed on the public sector as well as lock-in that emanates from investing in certain kinds of physical infrastructure and from legislative obligations imposed upon the agency. This worsens the existing financial and informational pressures on the public sector (PUB01, 2022).

Many governments have traditionally invested in infrastructure-intensive single purpose preventative measures such as dikes in the Netherlands. However, this makes investment very expensive given that they serve only one purpose. This also makes funding a major challenge as the public sector is less inclined to work readily with other development banks or funding instruments compared to the private sector (PAP01).

Feedback Loops:

Over the course of this report, a variety of feedback loops originating from public sector initiatives were identified. While they were highlighted in the respective case studies, their general implications were left undiscussed. The following section will expound more detail about these feedback loops.

One of the most prominent feedback loops observed was the close linkage between prevention and mitigation, particularly when the intervention was a structural (grey) infrastructure-oriented measure. In general, it appeared that an investment in prevention measures also boosted resilience by introducing a capacity to mitigate. This could be because a preventative structural measure (if designed well) can still reduce the damage caused by flooding even if it does not fully perform. Considering the case of the diversion canal and detention tank in Singapore, this can be clearly demonstrated. The Public Utilities Board invested heavily in the scheme in a bid to prevent flooding in a built-up area. However, even if the canal was operating at maximum capacity during a flood, it would still work towards draining flood water. This means that without the existence of the canal, the flooding could have been much worse. Thus, this case clearly demonstrates the link between prevention and mitigation despite their subtle difference.

The second major feedback loop that was visible was the link between mitigation and recovery. In general, improved mitigation facilitated faster recovery while better recovery aided mitigation from future flood damages. Looking into the end of the loop that connects mitigation to recovery, an increased investment in mitigative measures reduced the damages caused by floods. By reducing damages, less financial and non-financial resources would be required for the preparedness and response phases as there would be fewer fatalities, injuries and less damage to local infrastructure such as buildings and transport networks. This frees up precious resources to build back better. Focusing on the other end of the loop, increased investment in recovery measures translates to communities investing in long-run resilience boosting measures. To further explain, the recovery measure transforms the affected community by not only allowing it to return to its previous pre-flood state, but rather 'bounce forward' to a new normal with a state of higher resilience to flooding. This in turn means that communities are more likely to be able to minimise flood impacts in the future by mitigating damages. Investment in green infrastructure and nature-based solutions in particular reflects this pattern.

With reference to the case studies both the Central Chinese Government and the Shenzhen Municipality invested heavily in rain gardens along with other nature-based solutions to mitigate the impacts of flooding. However, by doing this, Shenzhen and other Chinese cities are not more equipped to handle pluvial and fluvial floods. The green infrastructure is able to absorb the impact of floods by providing spaces for water to accumulate instead of on built-up land. They also improve the drainage of water into the underground aquifers. Finally, they also slow the flow of water without water logging to reduce pressure on existing drainage systems. In doing so, Chinese cities are more resilient to rising flood risks and thus are able to better recover from flooding than before. The opposite mechanism is visible in the UK where social housing in London is particularly vulnerable to pluvial flooding. To recover from previous flooding, social housing estates in the Fulham & Hammersmith borough were able to invest in green-infrastructure such as bio-swales to improve drainage in densely built-up areas as well as to slow down the flow of water. This ensures that the social housing estates are now in a state of a new normal where they are better able to minimise the impacts of future flooding or heavy rainfall (which contributes to pluvial flooding). This does not mean that one must abandon grey infrastructure. On the contrary, combining to make a blue-green-grey grid would prove more beneficial. Grey infrastructure and its preventative capacities are still absolutely fundamental to invest in. However, nature-based solutions can add on to that by furthering ecosystem services as well as adding on to aesthetic appeal of infrastructure development such that there is less opposition to development (PAP01, 2022; PAP02, 2022). Overall, this loop could be exploited to drive climate adaption. It will be discussed in the emerging solutions section.

Finally, the last feedback loop observed was how investment in preparedness measures simultaneously had effects on preparedness, response & recovery. In general, it appeared that a better prepared community was able to make use of response mechanisms more efficiently. It also reduced pressures and demands on the public sector response services. This means that the public sector can better prioritise response and perhaps also divert resources to better recovery measures. Linking back to the cases, the use of SMS warning systems in Nepal ensured that there were fewer fatalities and injuries. This meant that more residents were able to evacuate prior to flash flooding. This also meant that fewer individuals would have to be rescued and that communities were able to safeguard more resources for later use. In the context of the Fort Bend case, communities were able to make better decisions through the public availability of high resolution through social media channels produced by the public sector. In general, the residents of neighbourhoods were able to evacuate in advance if they noticed the flood was advancing. They were also able to see if their loved ones in other areas were safe based on flooding footage of various neighbourhoods. The emergency response force was also able to better coordinate efforts and thus reduced damages from the flood.

Emerging Solutions:

Despite the above outlined challenges, there is space for hope in reforming the public sector and improving resilience for all stakeholders.

Governments increasingly recognise areas of cooperation. Countries in the North Sea region increasingly collaborate with Bangladesh and Vietnam to make use of wetlands to improve flood mitigation and provide other ecosystem services. This is due to the commonality in flood risk they face despite being in different regions and having different socio-economic and demographic contexts. There is a trend where the public sector is transcending national boundaries and making strategic win-win partnerships (PAP01, 2022). "It is like considering the world as a spaceship, and everyone is sort of the same crew in it" (PAP01, 2022, 15:08). There has also been a recent increase in cooperation with development banks such as the World bank and the Asian

Infrastructure Development Bank to fund flood resilience projects. Transnational cooperation of this kind has also aided in countries benefiting from lessons learnt elsewhere. Jakarta in Indonesia is known to undergo rapid subsidence due to high population density, rapid population growth, unsustainable use of groundwater and a lack of proper water and flood management, worsening existing flood risks. Surprisingly, Tokyo in Japan faced a similar situation nearly 40 years earlier. Tokyo's demographic and geographic context is similar to that of Jakarta. The Tokyo (and Japanese) government was able to make strategic interventionist infrastructure to arrest subsidence and greatly improve the resilience of Tokyo to floods. Thus, an opportunity to collaborate exists (PAP01, 2022).

Governments are starting to gradually decentralise flood governance capabilities. This means to distribute decision and planning power across the river-basin and local levels, instead of concentrating it at the top (central) level. This does not mean giving absolute power to the local level but giving more freedom to make spatial planning and take localised non-structural and on occasion structural measures. Large-scale structural measures may come under river-basin or national purview even after decentralisation. Decentralisation allows local level governments to expand the scope of stakeholder dialogues to better include spatial planners, NGOs and insurance companies. There also needs to be the translation of these risk dialogues into long-term legislation (PUB01, 2022; PAP01, 2022). Progress can already be seen. Most recently, Nepal has introduced a new disaster-management Act to mandate the decentralisation of disaster management and allow regional and local governments to play a bigger role. This allows Nepal's geographically diverse regions, especially the relatively low lying Terai region to invest in locally appropriate measures (Department of Hydrology and Meteorology, 2018).

Governments are increasingly making use of satellite data and GIS systems to create more up to date data sets of their jurisdictions. Newer methodologies to analyse and determine flood risks allow authorities to gather high resolution data at a faster pace and lower cost. "The use of GIS has really been embedded in the practice of spatial planning" (PUB01, 2022, 11:41). The practice of using such data is notable in China with the push for the Sponge City Plan. Prior to local interventions under the scheme, the government coordinated with academics and planners to identify flood points and areas with potential drainage and then demarcate spaces for green infrastructure. Such comprehensive data can be easily arranged and analysed using GIS systems which allow for better analysis and thus more nuanced insights.

Policy makers are increasingly recognising the utility of local and bottom-up generated knowledge, easing the burden on the public sector for data generation. Local residents often have better information of local contexts and everyday flood risks and can be found out through participatory mapping (PUB01, 2022). NGOs playing the role of consultants and bringing about new and innovative non-structural measures. Thus, many governments are able to make use of NGOs to inform practices and demands at a local level. Nepal's expansion of the SMS service to everyday citizens was originally raised by NGO Practical Action based on ground reports (PUB01, 2022; Practical Action, 2017).

The public sector is increasingly roping in large established private sector firms in various capacities to aid with flood management. This includes engineering oriented firms in conducting consultancies overseas (PAP02, 2022). The government of Nepal was able to quickly enter into an agreement with large private telecom players within the country to ensure the set-up of the SMS system and its accessibility to the general public in a time of need. On a different note, the workings Dutch Disaster Risk Reduction team involves a network of private consultancy firms which specialise in public sector hydrological engineering solutions such as RoyalHaskoningDHV and HKV. This allows the public sector to tap into private expertise to better cater to the flood-management needs of global South countries such as Myanmar, Mozambique and Ghana as part of its consultation process (PAP01, 2022).

Service-level agreements between the public and private sector can be used to ensure application of private sector innovations to ease the burden on the public sector while also encouraging other stakeholders to participate (PUB03). Presently, the government of the United Kingdom is in conversation with private sector insurance providers to better serve communities which face a higher than average flood-risk across the country (PUB01, 2022).

Maps as a form of communication have gained popularity. Most citizens have an intuitive understanding of maps. As maps can easily summarise and present complex data in a visually comprehensible manner, they are increasingly adopted to aid in communication. They also allow governments to better understand data generated by academics (PUB01, 2022; PUB02, 2022). The use of drone surveillance by the Fort Bend Emergency Management Authorities allowed for such data to quickly be depicted in a non-technical manner for ease of communication in an accessible (video) format.Similarly, some Dutch municipalities have been making use of maps to better understand the impacts and distribution of flood-risks and identification of priority areas through the use of the *Klimaat Adaptie* mapping tool (PUB02, 2022).These maps and other similar forms of data representation act as boundary objects which can better be identified and associated with flood risks at a local level. This association allows for the formation of new knowledge and resource networks that could better address flood-risks. Initiatives such as Water as leverage in Chennai, India and the Climate Campus in Zwolle, The Netherlands were able to encourage diverse stakeholder participation and the design of more locally appropriate solutions. These were also able to better attract investments (PAP01, 2022).

The public sector is now increasingly diverting funding and strategies to adapt to changing flood-risks. This allows for municipalities to develop in a more resilient manner. As a whole, there is huge potential for mitigating floods through spatial planning measures. This is often reflected in the water sensitive urban design being adopted in cities worldwide. Cities gradually transform from one that prioritises drainage only to a water-cycling city that is able to leverage water management (and flood defence) as an integral part of its everyday function (PUB01, 2022; PUB02; PAP01). Trends in the United States, China, Europe and Australia show a gradual shift in focus to mitigative measures and holistic water management to handle compound flood risks. This is particularly notable with the most recent major flood-related policies passed by legislation such as the Spong City Initiative in China and the Room for the River scheme in The Netherlands. These schemes are able to acknowledge the rising flood risk due to climate change in these countries and encourage adaptation to this situation rather than trying to only reduce flood risks, which may not be financially sustainable. Emerging countries such as those in South Asia, Southeast Asia and West Africa can avoid entering an infrastructural lock-in by making use of these multi-layer safety and water sensitive urban design approaches as being done in Europe and China (PAP01, 2022). The Water as Leverage initiative which is increasingly seeing public sector involvement is able to design such measures and contribute towards their implementation by being inclusive of multiple stakeholders. This has therefore, reduced the pressure on the public sector in the long-run.

“Nevertheless, the public sector is still in the ‘director’s seat’ and drives change. However, it must be done in cooperation with other stakeholders” (PAP01, 2022; 52:33).

Technology/ Aspect	**Diversion Canal & Detention Tank**	**Rain Gardens**	**SMS Flood Alerts**	**Small Unmanned Aerial Vehicle**	**Bioswales**
Level of Governance	National (Equivalent to Municipal)	National & Municipal	National & Regional	Municipal	Transnational & Submunicipal
Key Successes	Complex engineering measure was able to reduce risks while saving space	Megacity-wide nature-based solution able to mitigate damage and facilitate multiple value generation	Early-warnings available in a physically and financially accessible format to dispersed rural populations	Increases availability of high resolution flood data to adjust scarce response capabilities on a real-time basis	Improving existing vulnerable social housing estates to a higher state of resilience with potential for multiple value creation
Current Challenges	Engineering measures may not mitigate flood damage without	Nature-based solutions require more land area and further research and	SMS is only available in one (widely understood) vernacular	Requires data handling and operational specialists to assist local	Cost to benefit of such solutions are difficult to calculate and funding for these

	additional non-structural and structural measures	funding for large scale implementation to form a blue-green-grey infrastructure network	language and not all rural populations have access to mobile phones or a resilient telecom network	emergency services which requires external support that may not always be available in large numbers	projects may not be easily available at all times. Needs to be combined with other structural measures.
Emerging Solutions	Long-term policy to increase detention tanks in a distributed network across the city allows for a decentralised long-run and sustainable measure	Continued investment in research and development to create better designed solutions to local contexts and use of public-private partnerships for funding and implementation	Continued expansion of telecom network and SMS alerting services as well as improving provisions to empower local/regional governmental participation	Use of machine learning softwares to partially automate data processing and use of service level agreements to ensure availability of specialists on short notice	Roping in of social sector to improve maintenance mechanisms and gradual decentralisation to basin and local level authorities to coordinate implementation

[***Figure 30:*** *Summary Table for Public Sector Case Studies*]

Lake and Tank Restoration

Structural and ecological restoration of natural and man-made water bodies in Chennai, India

Communication	Coordination	Cooperation
Communicate with municipality and residents to demarcate water body restoration plans	Coordination with Public Works Department for landscaping and waste removal works	Prevention of degradation and future flood risk through engagement of residents

Prevention · Mitigation · Prepardness · Response · Recovery

CATCH pilot Zwolle

Community building strategy in the realm of the CATCH project from Climate Campus Zwolle: Espace room for awareness.

Communication	Coordination	Cooperation
Communication of real flood risks through educative games using new games inclusion of all community members.	Student teams built the escape room. Realization was made possibly by cooperation in Climate Campus network	Simulated real-life flood simulation raises awarenes and can be the foundation for better coordination among stakeholders.

Prevention · Mitigation · Prepardness · Response · Recovery

Functional Estimation System

Forecast-based financing of predetermined preparedness measures for downstream flooding in Togo.

Communication	Coordination	Cooperation
Use of radio stations to publicly broadcast warnings and preparedness advice in accessible manner	Coordination of funding and mechanism between Togolese Red Cross and German Foreign Ministry	Flood forecast model automatically triggers a fund release to power SOPs in downstream villages

Prevention · Mitigation · Prepardness · Response · Recovery

Volunteer Flood Mapping

Utilising Twitter alerts and geolocations to map flooding impacts and coordinate relief in Jakarta, Indonesia

Communication	Coordination	Cooperation
Commonly used app Twitter used as source for volunteer geographic information	Coordination between Jakarta Emergency Management Agency, Wollongong University and others	Citizen science through the use of mobile technology and free and open-source software

Prevention · Mitigation · Prepardness · Response · Recovery

Cash Transfer Systems

Using SMS and voucher management systems to ensure 100% reach in cash transfer programmes in Cambodia.

Communication	Coordination	Cooperation
Communication between local NGOs with government to improve provision of cash through ID	Publicly available listings allowed potential beneficiaries to request assistance for cash transfers	Flexibility in utilising cash transfer allowed for rapid recovery by affected beneficiaries post-floods

Prevention · Mitigation · Prepardness · Response · Recovery

Lake Restoration

Nature-based Socio-technological Solution

Restoration of lakes to prevent flood-risks

Prevention — Mitigation — Prepardness — Response — Recovery

Best-practice description

- Madambakkam lake in southern Chennai underwent a complete ecological and hydrological restoration
- Public Works Department, Rotary Club and local residents were involved in assisting with the restoration works
- Special reinforcement works were done to ensure the sustained preservation of the waterbody

Communication

- Environmentalist Foundation of India was able to communicate clear engineered plans with the PWD
- EFI was able to make use of wall paintings to communicate social messages to better inform resident populations

Cooperation

- Funding was provided by the Sun Network through another NGO Rotary Club of Madras
- Local residents were able to hold the public sector accountable for its contributions through the EFI

Coordination

- PWD was able to conduct geo-technical works during the pandemic restrictions as it it involved fewer people and more machinery
- EFI was able to gather and coordinate volunteers immediately after the lift of the pandemic restrictions to assist with ecological restoration efforts

Challenges, Solutions & Scaling

- Lakes are part of a greater system of tanks and lakes that store pluvial flood waters. System-wide restoration is needed for long-term effectiveness
- Funding needs to be sustainable. IT sector firms could contribute to this as part of their Corporate Social Responsibility
- There is a unique feedback loop connecting flood prevention and flood recovery, as enhanced prevention allowed for faster recovery which improved societal investment in preventative measures

Society - Report of Best-Practices

1. Prevention

1.1 Nature-based Socio-technological solution

1.1.1. Background

Chennai is one of India's largest metropolitan areas, located on the Southeastern coast along the Bay of Bengal in the state of Tamil Nadu. Like many regions of the Indian subcontinent, Chennai receives a large proportion of its rains in the form of intense monsoon showers. Chennai gets the largest proportion of these rains between October and December during the Northeast monsoon. However, the city got unusually high rainfall in 2015 which led to severe and widespread flooding. The 5 day average rainfall was 399 mm compared to the usual 40.6 mm indicating 883% excess (National Disaster Management Authority [NDMA], 2016).

However, even in years of normal rainfall, Chennai has faced flooding in its predominantly flat terrains. Chennai has also been historically covered by a large number of natural and manmade lakes which have been used to capture stormwater from heavy monsoons and prevent flooding. Madambakkam lake is one such example. Madambakkam lake was created in the 8th century by King Kulonthaga Chola II for the purpose of agriculture irrigation, flood prevention and domestic water supply in this region of southern Chennai (Environmentalist Foundation of India [EFI], 2020a). High levels of pollution and encroachment for land developments have shrunk the water body and worsened flood-risks in the region. Much of this pollution comes from the surrounding urban population and contains large amounts of plastics which tend to clog the natural drainage channels that lead to and from the lake. Development of the Information Technology sector on the Southern side of Chennai tremendously increased the demand for office spaces and residential areas as the population grew rapidly as more land area was dedicated to the IT Corridor and industrial estates (EFI, 2020a, Manohar & Muthiah, 2016).

Madambakkam lake was previously connected to other lakes in Southern Chennai and acted as a catchment for excess water from other lakes and thus reduced flooding in the region. This was part of the traditional *eri* system used in the region to capture pluvial flood water and store it for the dryer seasons. However, recent developments have blocked this natural flow of water between water bodies exacerbating the shrinkage and impairing its functions. A lack of dredging and maintenance of this man-made waterbody has also impacted its water storage capacities, worsening floods in the region and warranting urgent restoration measures (EFI, 2020a).

The Madambakkam lake is located 11.2 km from the coast along the bay of Bengal and is surrounded by smaller hills making it a natural point for water accumulation in Southern Chennai. Thus it was strategically excavated and expanded in the 8th century and served the local population for a period of 1,200 years and thus played a central role in capturing flood waters. The lake covers around 232 acres of land, making it a substantially large lake that serves the city's flood defence and water needs even to the modern day (EFI, 2021b).

1.1.2 Justifications

Chennai is among the major cities in the Asia-Pacific that faces high risk of flooding as well as water scarcity and is located in a water stressed region with relatively erratic monsoon rains which increase the risk of flash floods. A solution that can both alleviate flooding as well as accumulate water would be an ideal combination to improve Chennai's long-run resilience (NDMA, 2016).

Chennai has expanded rapidly, hindering its natural hydrology from its ability to drain water. Ever since the growth of the city from a British trading post, a larger and larger area has been covered by concrete buildings and paved roads and many of the local water bodies, wetlands and rice fields have disappeared. This significantly worsened the effects of the floods that impacted the city 2015 which was the worst in a century due to substantially higher than normal precipitation levels experienced in that monsoon.The region's people had already developed a cascading system of water bodies to store river and flood water and conserve it during the dry seasons known as the *eri* system. This was developed over centuries and ensured a historically higher level of resilience to flooding. Chennai is currently highly vulnerable to changing climate patterns as its hydrology has been tampered with to the extent that it is unable to resiliently handle normal northeast monsoonal rainfall leading to annual waterlogging and disruptions to daily life. Thus, waterbody restoration is of urgent importance for the city's survival (Manohar & Muthiah, 2016).

[***Figure 1:*** *Map depicting water bodies and lake (eri) systems in the Chennai metropolitan region (Manohar & Muthiah, 2016)*]

[***Figure 2:****Traditional cascading hierarchy of water bodies in the Tamil speaking region of India including Chennai (Manohar & Muthiah, 2016) - Madambakkam Lake is a Yeri*]

The restoration of the Madambakkam lake could improve flood-resilience and water security for around 500,000 residents in this mixed rural-urban area, provide irrigation for 2000 acres of cultivated land and overall drinking water for the surrounding 10 villages (EFI, 2020a). High levels of organic waste and centuries of silt deposits put the lake at risk of algal blooms and the resultant eutrophication. This could severely impact the lake's biodiversity. It could also worsen the clogging of the lake's natural water flow. Desilting is urgently needed to restore its flood-preventative capacity (EFI, 2021b).

[***Figure 3:*** *Satellite Image of Madambakkam lake in 2002 (EFI, 2020a)*]

[***Figure 4:*** *Satellite Image of Madambakkam Lake in 2019 (EFI, 2020a)*]

1.1.3. Best-practice Description

In an effort to improve flood and overall water resilience in southern Chennai, the EFI undertook the restoration of the Madambakkam Lake. The efforts involved multiple stakeholders at various stages and was deemed as one of the organisation's most successful case studies.

Firstly, solid waste and weed growth were removed over the course of a week. This would significantly improve the flow of water into and out of the lake as these wastes, especially plastic bags, tended to collect in the lake's inlets and outlets interfering with water flow. This was heavily driven by local volunteers who usually spent time on the weekends to assist with picking the waste by hand (EFI, 2020b).

After the initial clean-up, more heavy geotechnical works such as desilting and dredging was conducted by the Public Works Department [PWD], Tamil nadu's primary water supply department who have the resources and expertise for larger engineering works. This facilitated the rapid ecological and hydrological restoration of the lake's functions. A variety of geotechnical works were constructed including double embankments, recharge wells and islands (EFI, 2020b).

[***Figure 5:*** *Double Embankment along Madambakkam Lake (EFI, 2021b)*]

Double Embankments were constructed on the side of the lake to arrest erosion and to prevent future clogging of water flow through illicit waste disposal (EFI, 2020b). Excess silt dug up from the lake was repurposed to create the double embankment of 18 feet. This improved the flood resilience of the lake and reduced the chance of solid waste disposal (EFI, 2021b). A taller and wider embankment can significantly reduce the chance of the lake overflowing or bursting the bund. Hence, a double embankment provides two such layers of protection against pluvial/fluvial flooding (Akshatha & Shankar, 2022; EFI, 2021b). The embankment was 2.5 kilometres along most of the edge of the lake (EFI, 2021b).

[***Figure 6:*** *Percolation Well in Madambakkam Lake Bed (EFI, 2021b)*]

Recharge Wells were dug into the lake bed to create areas of higher depth to catalyse the percolation of water into the groundwater table. Given Chennai's water scarcity, rapid percolation would be beneficial in recharging drying aquifers. Furthermore, the desilting and strategic deepening of the lake increased its holding capacity, allowing it to be able to deal with unusually heavy rainfall in a context where monsoon patterns have become increasingly erratic (EFI, 2020b).

Neem Pockets or small islands populated by native neem trees were planted to provide nesting habitats for local and migratory birds. This would aid in the ecological recuperation of the lake as wetland areas grow to add on to the water retention as well as other hydrological capabilities (EFI, 2020b). Concentric Circle Islands were constructed near the foreshore to prevent further erosion of the embankment while redirecting water flow across the lake. This ensures that the embankment has a lower risk of collapse which would have serious consequences if the lake breaks its banks in the monsoon (EFI, 2021b).

The above outlined practices have also been proposed in other cities in the region such as Coimbatore (western Tamil Nadu) and have been supported by academic and engineering experts. In general, the bunds (embankments) and recharge wells play a key role in ensuring flood defences are not eroded over time and can continue to prevent pluvial and fluvial flooding (Natarajan et al., 2020).

1.2. Evaluation

1.2.1. Communication

The entire project was initially undertaken by EFI. However, the EFI was able to reach out to and communicate with various stakeholders which were directly and indirectly affected by the decline of Madambakkam Lake. This included other civil society organisations, local residents, the PWD as well as a private firm.

The Sun Television Network's foundation provided funding through the Rotary Club of Madras, another prominent civil society organisation in Chennai. Given the Sun network’s large size and profits, it had sufficient financial capital to fund the major geo-technical works (EFI, 2020a).

The PWD carried out the majority of the restoration works planned by the EFI after consultation with ecology and engineering experts who volunteer within the organisation. Thus, the EFI is able to set up a consistent stream of communication and information within the organisation as well as with public sector stakeholders culminating in a clear action plan and its rapid execution (EFI, 2020a).

Multiple stakeholder coordination allowed for a rapid restoration of the lake from July 2020 to October 2020, prior to the peak of the Northeast monsoon. Wall paintings and social messages were used as a tool to gather local support and to raise awareness of the importance of water body restoration. These paintings and messages were usually made by local residents, especially youth actors who were able to better network and raise support from local residents. Thus, EFI was able to successfully leverage its position as a connector organisation to communicate and engage with diverse stakeholders in an efficient manner (EFI, 2021b).

[***Figure 7:*** *Wall Painting to raise awareness of madambakkam Lake restoration (EFI, 2021b)*]

1.2.2. Cooperation

The EFI was also able to distribute work and involve stakeholders accounting for their respective powers and capabilities.

After the devastating floods of 2015, higher levels of general awareness ensured local populations and residents’ support for lake restoration efforts. Residents are typically poorer to middle class and did not have substantial financial resources. However, they were able to provide manual labour in clearing solid waste and weeds from the lake. They were also able to paint messages to remind other residents of the importance of the lake and to avoid illicitly disposing of solid waste. Thus, they also have the power to change local behaviours and habits (EFI, 2020a).

The PWD was able to remove three to four feet of silt to prevent eutrophication (algal blooms) and to increase depth and natural percolation to the ground water table. Protective fencing was installed to prevent illegal waste disposal by local inhabitants. This was erected by civil society organisations in coordination with the PWD. Engaging the PWD ensured that the lake could be restored without a high cost. As the PWD holds machinery as part of assets, it was able to make use of its latent capacity for this project. In doing so, the PWD is able to improve the function of a water body under its purview while still being supported by private funds from the Sun TV network who is not a direct stakeholder and experts and volunteers from the EFI. The restoration could also reduce costs of future interventions in the region for the PWD (EFI, 2021b).

Civil society plays a vital role in holding government’s accountable to flood-risk standards. In this case, the EFI is able to follow up with the PWD to ensure the follow-through of restoration plans. Pressure from the Rotary Club of Madras also ensured that the PWD contractors were held accountable for the completion of geo-technical works. Thus, civil society was able to exercise the right to accountability in a relatively democratic system and engage in a bottom-up initiation of flood-risk prevention (Bouman-Dentener & Devos, 2015; EFI, 2021b).

1.2.3 Coordination

Coordination with multiple civil society, governmental and private stakeholders ensured that the ecological restoration works continued well into the pandemic in June 2020, in a period where there were many restrictions. This ensured the lake had enough capacity to store and percolate water for the north-east monsoon season in 2020 and 2021 (EFI, 2021a).

Even though local volunteering was not permitted under COVID emergency regulations, dredging and embankment and other geotechnical works by the PWD were able to continue. Thus, the mechanisms through which different stakeholders contribute to this initiative can be seen. As geotechnical works predominantly require machinery and a small pool of operators, coordination and implementation of these works became more feasible in the context of the pandemic. (EFI, 2021a).

After December 2020 regulation relaxations, local residents were able to volunteer once again to keep the lake clean and ensure drainage points were not choked with plastic pollution. They also aided with planting trees and other native vegetation to further stabilise the banks of the lake as well as to improve the aesthetics. These types of intervention involved a larger pool of volunteers and local ecological experts and thus was only possible after pandemic restrictions were temporarily relaxed (EFI, 2021a).

[***Figure 8:*** *Tree Plantation and Clean-up by Local residents around Madambakkam Lake (EFI, 2021a)*]

NGOs play a central role in involving the most vulnerable populations in flood resilience initiatives. The EFI's engagement of highly vulnerable residents who are at risk of floods and whose livelihoods depend on the lake's proper function ensured the long-run sustainability of the initiative as well as the general resilience of the local population (Bouman-Dentener & Devos, 2015; EFI, 2021b)

[***Figure 9:*** *Aerial View of Madambakkam Lake Restoration (EFI, 2021b)*]

1.3. Barriers, Expectations and Solutions

Despite the success of the lake restoration scheme, there appears to be a continued risk of pressure on encroachment of the lake and its pollution due to the region's rapidly increasing population. This means that in the long-run newer residents will have to be roped into the efforts to continue the preservation and maintenance of the lake. Larger-scale educational and awareness activities may be required on top of existing interventions (EFI, 2021b).

The EFI has managed to improve multiple local lakes in Chennai as well as in other parts of India. Lake restorations in Tamil Nadu cannot have a large-scale impact without further support from the public sector to scale this to a regional level. This is because these water bodies work together in the *eri* network and thus cannot be viewed in isolation but as part of a regional flood management system that can spill over district boundaries. There needs to be a governance structure that encourages civil society initiatives, participation and resource utilisation to sustain a larger scale initiative of this nature (EFI, 2021b; Bouman-Dentener & Devos, 2015). Downstream lakes such as the Sithalapakkam Lake where excess water from the Madambakkam lake flows into, was recently completed. However, a network-wide restoration is required to make full use of the *eri* system to prevent flooding (EFI, 2022).

There needs to be a more sustainable way to finance civil society initiatives due to the meagre resources available to the local community. Working with the private sector may help in improving financial resource availability, however it is a tricky process to convince large private sector firms. It may be possible to rope in the firms in the southern industrial estates as many of them already sit on what were previously either wetlands or lakes, and thus could contribute to the preservation and restoration of the remainder of the *eri* system (Bouman-Dentener & Devos, 2015).

There has been a push for flood prevention and mitigation efforts from the Greater Chennai Corporation to improve and restore water bodies across the city. This scheme involves joint civil society and private sector engagement to ensure long-term sustainability and a whole-of-society integration to achieve flood resilience (Natarajan, 2021).

This particular case sees the involvement of all three key stakeholders, making it a unique best-practice given the heterogeneity both within and between the public, private and social sectors. This whole-of-society integration plays a key role in allowing stakeholders to synchronise efforts and to keep each other in balance to achieve a successful outcome. In an era of increased flooding, such initiatives have allowed the area to build back better (or rather restore what has gone into severe decline and disuse). Thus a feedback loop linking prevention and recovery is observable. This shall be discussed in the conclusions section.

CATH pilot Zwolle

Socio-technological Solution

Community building strategy in the realm of the CATCH project from Climate Campus Zwolle: Espace room for awareness.

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description

• The main aim of the pilot in Zwolle was to raise awareness among average citizens in the region to increase preparedness in the case of floods.

• To that end, serious games using new technology were developed. The first consisted of a mobile escape room, the so-called Adapt of BTrapped. The second, Garden Battle, is a kind of SIM City game playing out in Zwolle's digital twin city.

(Climate Campus, 2020)

Communication

• Communication of citizen insights through involving them in serious yet fun games is a quite unique way of active citizen involvement.

• The assembled data is valuable because it enables the municipality to make better policy for the inhabitants

Cooperation

The games "improved cooperation of residents with the municipality in that it raised awareness, also the escape room involves conversations with players after the game. This provides an excellent opportunity to zoom in on the specific neighbourhood the players live in and the vulnerability of their neighbourhood to floods"

Coordination

Playing the game enhances risk perception & awareness of possible measures and that risk perception correlates positively with the willingness to take protective measures, such as the disposal of paved gardens in favour of greenery, placing a rainbird, making a green roof

Challenges, Solutions & Scaling

• "We try to […] share knowledge and stimulate collaboration to develop joint solutions. For instance, our findings and learnings from the serious game pilots have been presented to the partners in the Climate Campus network and led to events where the escape room is being used

• Finally, in regard to obstacles to potential collaboration, the stakeholders from Climate Campus conclude, "In times of crisis, organisations tend to retract to their core business. But to overcome the climate change challenge, collaboration and mutual trust is key"

2. Mitigation/Preparedness

2.1 Socio-technological solution

2.1.1. Background & Justification

Climate change is suggested to exacerbate the effects of pluvial but also coastal flooding, predominantly in the urban area. This, in turn, causes great uncertainty and worries for the concerned governments and citizens (Wang et al., 2021; Yin et al., 2020). In the foreseeable future, many delta cities will be more affected and therefore have to be prepared to mitigate the effects of flooding for their citizens (PAP01; PAP02; Tessler, 2015). From those cities, especially small and medium-sized cities and municipalities, often lack the resources to implement and maintain large-scale grey infrastructure and the like. Hence, they rely even more on active and prepared citizens to mitigate the impacts for these when flooding happens (Cortekar et al., 2016.; Yin et al., 2020). Many of these delta cities are located in the north sea region. The North Sea Region encompasses coastal areas including Denmark, Flemish regions of Belgium, eastern parts of the UK, the north-west of Germany, the south-west of Sweden, northern and western parts of the Netherlands and the entire territory of Norway (Climate-ADAPT, n.d.).

To address this large region's need for increased climate resilience, INTERREG funded several projects from 2014 to 2020. One of them, CATCH, stood out in the way it addressed cities particularly vulnerable and included civil society. CATCH stands for 'water sensitive Cities: the Answer To CHallenges of extreme weather events (Climate-ADAPT, n.d.; North Sea Region, n.d.)

The critical area of focus is small to large cities. As stated before, CATCH initiators confirm that midsize cities have special needs when facing the challenges of climate change adaptation in terms of extreme weather events that increase the likelihood of flooding, especially for Delta cities. "In the North Sea Region, 80% of the population live in urban areas, of which a majority lives in midsize cities. Due to its scale, limited resources and expertise and tight connection with the surrounding region, midsize cities face a number of specific challenges to deal with climate change adaptation compared to large cities" (North Sea Region, n.d.).

To show how those cities, with the right resources and in cooperation with Interreg partners, can become climate-resilient, seven pilots were initiated. These seven pilots are complemented with guides, usable generic tools and practical suggestions to foster further uptake in the North Sea Region (North Sea Region, n.d.).

One particular pilot was very successful in employing technology and virtual reality in the form of serious gaming to include civil society. This pilot was carried out with the Climate Campus. Climate Campus is "a network of governments, education and research institutions, entrepreneurs and social initiatives collaborating to build a climate-resilient IJssel-Vechtdelta", Netherlands (Climate Campus, 2022).

2.1.2. Best-practice description

The main aim of the pilot in Zwolle was to raise awareness among average citizens in the region to increase preparedness in the case of floods. Improved decision-making and critical thinking related to the right actions during a flooding event have the potential to greatly mitigate the detrimental consequences of false actions in such critical situations. Furthermore, community building and coordination were to be improved. To that end, serious games using new technology were developed. The first consisted of a mobile escape room, the so-called *Adapt of BTrapped*. The second, *Garden Battle*, is a kind of SIM City game playing out in Zwolle's digital twin city. In the game, residents are challenged to create gardens and neighbourhoods that allow for more green water space (Interreg, n.d.).

The development of both projects was realised in collaboration with civil society organisations. Key actor in the CATCH pilot from Climate Campus points to the collaboration with civil society organisations such as water board Waterschap Drents Overijsselse Delta and students from various educations (SOC, 2022).

The coordinator in the CATCH pilot from Climate Campus explains that for the escape room, "We involved students from the Game Studio 038Games from Windesheim University UAS, and from CIBAP Vocational College for Design, to develop the game Adapt or BTrapped and build the climate escape room, [...] With the help of The Great Escape, an escape room company in Zwolle. Also, they [students] received input from Nanco Dolman, leading expert from Royal HaskoningDHV and involved in the CATCH project, in the development of the Decision Support Tool" (SOC 02, 2022).

Concerning the second game *Garden Battle*, the serious online game was developed with Grendel Games, a serious game developer. Member of Climate Zwolle explains the online game is "challeng[ing] citizens to take the most effective measures to make their homes and streets climate-resilient. An important basis for the game is the digital twin city of Zwolle, a virtual tool that comprises a lot of valuable data about the municipality of Zwolle" (SOC02, 2022). The interviewee furthermore explains the process of the game development and testing: "The game was first launched March 2021 for a small group of citizens whom we considered to be the pioneers to test the game prototype. After that, the game was launched in two neighbourhoods in Zwolle, with the option to take collective measures with the neighbourhood to make it more climate-resilient.

In the game, we provided suppliers of climate adaptive products such as rain buds, etc., to showcase their products in the game so that players could virtually 'buy' these products while playing the game. These suppliers were HORNBACH, Tuinland Zwolle, Rawinso, Rainwinner, Stadshovenier Zwolle and Stip Hoveniers. In this way, we could involve commercial stakeholders who also provided prizes for the players to win if they won the game. At the end of May, we organised a press meeting with all the winners of the game and the alderman, to raise awareness in the entire city, and to award the winners" (SOC02, 2022).

After the completion of the game, the quantitative results of downloads and usage of the game were quite promising. The Climate Campus respective involved stakeholders stated the following in terms of numbers: "The results of the game are that a total of over 31.350 unique persons were reached with the social media campaign between March and end of May 2021, with a median CTR of 1,26% and a unique CTR of 8,41%. A total of 261 citizens of the two neighbourhoods downloaded the game between March and 1st of June 2021.172 of these citizens claimed their online garden and played the game" (SOC02,2022).

2.2. Evaluation

2.2.1. Communication

The data collected through the games can be used to improve policies. Communication of citizen insights through involving them in serious yet fun games is a quite unique way of active citizen involvement. The Coordinators from Climate Campus expand that "The assembled data is valuable because it enables the municipality to make better policy for the inhabitants. The Garden Battle was built in 2020-2021 and made use of a lot of data from the twin city of Zwolle, especially concerning hotspots vulnerable to flooding and heat stress" (SOC02, 2022).

2.2.2. Cooperation & Coordination

Team members of Climate are confident that cooperation before and during floods with civil society has been improved through playing the serious games: "In June, we [...] asked applicants to participate in a survey which was carried out by a social science PhD-researcher from Groningen University Rijksuniversiteit Groningen who conducts research into the behaviour of people in relation to climate change. This concerned the extent to which people perceive climate change and extreme weather events as a risk and the correlation with their willingness to take measures to protect their house, garden and neighbourhood. The survey was spread in the last flight of the social media campaign in June, and 45 citizens took the survey. [...] The survey was, of course too small to draw valid conclusions, but it does seem to indicate that risk perception and the willingness to take measures seem to positively correlate "(SOC02, 2022). The interviewees furthermore specify that the research "indicates that playing the game enhances risk perception as well as awareness of possible measures and that risk perception correlates positively with the willingness to take protective measures, such as the disposal of paved gardens in favour of greenery, placing a rainbird, making a green roof, taking care of bees and butterflies, etc." (SOC02, 2022).

Finally, communication, cooperation and coordination between citizens and government officials has likely improved. The interviewees conclude that the games "improved cooperation of residents with the municipality in that it raised awareness, also the escape room involves conversations with players after the game. This provides an excellent opportunity to zoom in on the specific neighbourhood the players live in and the vulnerability of their neighbourhood to floods and heat stress, etc." (SOC02, 2022).

2.3. Challenges, Expectations and Solutions

Concerning knowledge sharing of this unique project which included local knowledge, Climate Campus coordinators explained that multiple actors were involved, and communication to external stakeholders was undertaken. "We try to […] share knowledge and stimulate collaboration to develop joint solutions. For instance, our findings and learnings from the serious game pilots have been presented to the partners in the Climate Campus network and led to events where the escape room is being used (SOC02, 2022).

Concerning smart collaboration with the developers of the technologies, Climate Campus Coordinators explain: "The technology of digital twins which enables partners to incorporate lots of valuable data is important for a wide group of stakeholders involved in climate adaptation. Partners as Esri in the Climate Campus network are important developers for such twin cities. But they rely on municipalities, other civil organisations and citizens for their valuable input. So smart collaboration is key to make full use of the valuable data to develop effective policies and measures "(SOC02, 2022).

Finally, in regard to obstacles to potential collaboration, the stakeholders from Climate Campus conclude, "In times of crisis, organisations tend to retract to their core business. But to overcome the climate change challenge, collaboration and mutual trust is key" (SOC02, 2022) .

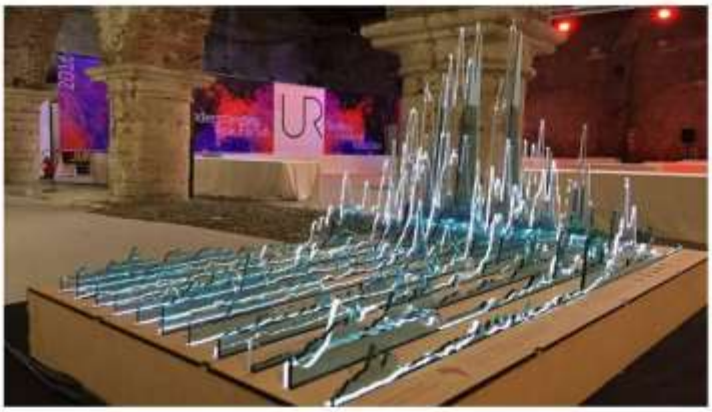
Functional Estimation System

Socio-technological Solution

Use of self-learning algorithm to conduct forecast-based financing of preparedness measures

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description



- Togolese Red Cross set up a FUNES system to analyse overflow of water from Nangbeto dam
- Data inputs are used to provide a 48 hour prediction of overflow
- If thresholds are crossed, a early warning message is released and earmarked funds are used for preparedness measures

Communication

- The Togolese Red Cross is able to communicate with other civil society organisations and the public sector of the local situation in downstream villages
- Partial automation of data collection through SMS ensures ease of access to high resolution data for predictive model

Cooperation

- Use of service level agreement with German Foreign Ministry to set up seed funds and ensure appropriate utilisation
- SOPs developed for each village to prepare locals to take preparedness measures in time

Coordination

- FUNES model is able to integrate diverse sources of data from public and social sectors to develop accurate predictions
- Pre-made agreements with local radios and use of loud speakers to issue early warning to people without access to SMS or those who are less literate

Challenges, Solutions & Scaling

- Requires further public sector cooperation and funding to be able scale-up to a national or basin level
- Capacities of at-risk communities need to be improved to ensure they are able to take preparedness measures in a timely manner
- There is a feedback loop which shows that preventative preparedness initiatives parallely improve response and recovery from flooding

3. Preparedness

3.1 Socio-technological solution

3.1.1. Background:

Togo is a small country located in Western Africa and has a tropical rainforest climate. The Mono river, which forms the border between Togo and Benin was dammed in 1968 for the purpose of generating hydro-electric energy for both countries in the Nangbeto site (African Development Bank, 1994). Ever since then, communities who live downstream from the dam have faced flood risks from overflow of the dam during times of high precipitation. The Mono River Basin was flooded in 2010 displacing 6000 people and causing extensive damage to crops leading to massive disruption of livelihoods. Climate change continues to exacerbate these flood risks which disproportionately affect the health and wellbeing of those in the global South. Downstream communities are particularly vulnerable as there is no other infrastructure that acts as a preventative mechanism to combat fluvial flooding. The Togolese Red Cross requested US$ 250,000 in relief funds from the International Federation of Red Cross and Red Crescent which was to be spent after the occurence of the flood. If a forecast was available, necessary funds could have been released upto 36 days prior to the beginning of major flood events in the basin. This means that the ability to predict would have enhanced the preparedness of vulnerable downstream communities thereby reducing the pressure and funding for resources to drive flood responses which is useful in resource scarce regions (Climate Centre, 2019).

3.1.2 Justification

The Mono basin, which is located in southeastern Togo, is particularly vulnerable to flooding due to close proximity of farmland and poorly constructed settlements to the river banks. This places a large section of the region's population under high flood risks while having insufficient resources to be able ensure their resilience. Togo has a high risk towards climate change impacts ranking 135th of 180 countries in the ND-GAIN index. This is because a large section of Togo's population is engaged in subsistence agriculture and are well below the global poverty line. There will be an increase in the number of days with at least 20 millimetres of rainfall leading to greater variability in rainfall patterns over time. This therefore increases the susceptibility of overflows in the Nangbeto dam due to sudden increases in inflows that could push water levels in the reservoir above its storage capacity (Dove et al., 2021).

Most early-warning systems often are unable to predict flood-risks at a high enough resolution at a localised scale and often fail to disseminate information for preparedness of vulnerable communities as a top-down approach is used (Perera et al., 2020). Since 2009, the Togolese Red Cross has set up tri-coloured water gauges to trigger early-warnings through megaphones (speakers) and emergency mobile phones in 112 villages with a total population of 100,000 people (German Red Cross, 2022). This follows-up from the deficiency of an early-warning system. That is, while early-warning systems can communicate the impending disaster, it does not provide information to define actions for the following stage in the DRM cycle: preparedness. This means that early-warning systems are useful but have a major drawback in terms of better contributing to preparedness among the vulnerable sections of society (German Red Cross, 2017; Perera et al., 2020).

The Functional Estimation (FUNES) Forecast based Financing (FbF) system ensures that the Togolese Red Cross and the Togolese National Platform for Disaster Risk Reduction are able to intervene in vulnerable communities in advance of an impending flood (Climate Centre, 2019).

3.1.3. Best-practice Description

FbF systems can be used to release funding for pre-determined humanitarian activities based on flood forecasts to bolster and catalyse preparedness mechanisms further downstream. However, this system cannot work in isolation but comes paired with other related solutions as inputs (such as flood forecasting) and outputs (for example designing preparedness procedures) (German Red Cross, 2017). A FUNES model forecasts and models the value of a dependent variable by considering forecasts for various independent variables and looking for historical patterns.

In this case, the FUNES system at Nangbeto dam is able to measure the rate of inflow and local precipitation data to estimate the volume and time that an overflow or advance release of water would be required (Aquaveo, 2017; Climate Centre, 2019). A Funes model creates a set of forecasted scenarios which are compared to historically observed data to generate rankings of similarity. There are three major approaches to FUNES models namely: the deterministic approach, the ensemble approach and the dimensional analysis.

In the deterministic approach, a similarity ranking can be used to create a deterministic model where historical points are identified in a model with multiple dimensions. Each dimension is an independent variable and a final dimension for the dependent variable is added to create a 'response surface.' More strongly correlated variables can be assigned a higher weight by using the 'inverse distance weighted' method. The forecast for the dependent variable value can be determined by finding the appropriate multi-dimensional point based on measurements input from the independent variables. The forecast is a single value but the certainty of its occurrence is not provided (Aquaveo, 2017).

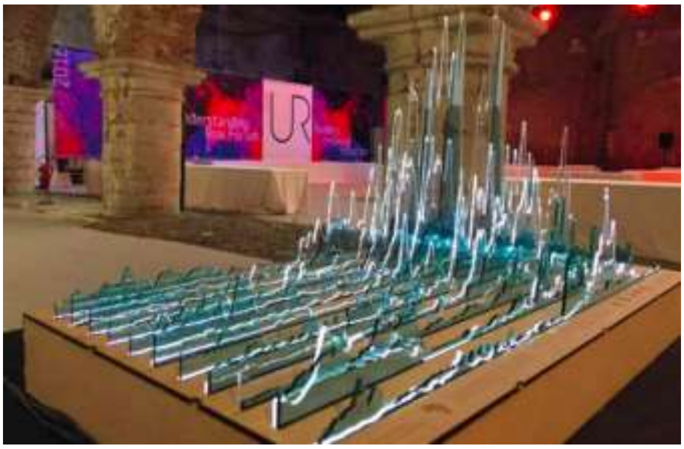
In an ensemble approach, an 'n' number of most similar historical observations are selected to form an ensemble. The differences in maximums, minimums and means of the response variable are plotted to form one response surface each. Based on differences in the respective response surfaces, a better understanding of the certainty of these predictions can be derived to generate a range of the response variable for a given set of observed values (Aquaveo, 2017).

For conducting a dimensional analysis, each independent variable is separately investigated. The independent variable is plotted against the dependent variable and the probability that a given value crosses a threshold based on the forecast value is calculated for each variable. The probabilities are then combined into a single probability with weights assigned as necessary (Aquaveo, 2017).

The FUNES model cannot be used by itself to extrapolate predictions as it can only predict based on what are the maximum values it remembers. Thus it can only be used to predict and forecast flooding within the parameters of the base data it is fed to utilise for model generation. The FUNES Universal software package allows the user to plot time series, manage variables and generate response surfaces to conduct deterministic, ensemble and dimensional analysis. Users of the software are trained to ensure that they are able to generate an appropriate model for prediction (Aquaveo, 2017).

While the above limitation may make FUNES models seem less useful, they are highly versatile and can take a variety of different data inputs to generate a predictive model. This makes it highly useful due to its flexibility (Aquaveo, 2017). The FUNES model for Nangbeto dam posts a 2-day risk level forecast unique to each village located downstream from the dam in Togo (Climate Centre, 2019). A self-learning algorithm is used to measure and predict overspill volumes from the Nangbeto dam (Climate Centre, 2017a). When the threshold for any input variable is high, leading to an estimated overspill which exceeds maximums, the dam operators warn humanitarian volunteers through a radio system to trigger the flood preparedness procedures further downstream. This can include reminding people of evacuation routes, tips on safeguarding documents and fortification of houses (Climate Centre, 2017a; German Red Cross, 2022). Evacuation drills are conducted to prepare downstream communities of 15 Togolese villages (Climate Centre, 2017a; Climate Centre, 2017b). Standard Operating Procedures (SOPs) are used to define which actions are taken based on thresholds for flood occurrence. This has enhanced the preparedness of vulnerable communities most likely to be affected by the release of excess water from the Nangbeto dam. These SOPs are financed by a dedicated fund where budgets are pre-allocated depending on the forecasted flood scenario (German Red Cross, 2017).

This FbF approach to preparedness won an award in the United Arab Emirates for its innovation and enhancement of collaboration across various diverse stakeholders (Climate Centre, 2017c)



[***Figure 10:*** *Visualisation of Functional Estimation Model of Nangbeto Dam (Climate Centre, 2019)*]

3.2. Evaluation

FUNES is a useful technology that can be implemented at a local level and is potentially replicable in various downstream communities worldwide. It works in tandem with civil society organisations to integrate diverse stakeholders. However, scaling this system up is challenging without public sector support and private investments.

3.2.1. Communication

The use of easily accessible and affordable communication technologies as well as strategic automation allowed for ease of communication between stakeholders.

Rainfall reading metres upstream are able to transmit data to dam operators through an SMS making data easy to access and read. This automation ensures that readings are available in consistent intervals and are easier to analyse and input into the FUNES system. Given the ease of SMS use and access in the global South, this technology becomes useful in transmitting data in areas with low internet penetration, especially in rural Togo (Climate Centre, 2019).

A colour-based early warning system schematic was developed for ease of understanding by NGO workers as well as residents of the downstream villages. Grey is for very low-risk, yellow for low risk, blue for moderate, orange for high risk and red for very high risk. Each warning for risk also comes with instructions for the local community to follow to alleviate and prepare for the incoming flood risk as part of a 5-point scale system. As the SOPs for each village are unique and are contextualised to local needs and situations, it is easier for resident populations to follow instructions. This ensures that villagers are able to make better use of aid materials such as water purification tablets and deploy mosquito nets in time, preventing negative impacts on health and safety (Climate Centre, 2019; Climate Centre, 2017b).

Radio stations were able to pre-record Togolese Red Cross employees and volunteers to publicly broadcast information in a way that was more accessible to vulnerable downstream communities. Lower levels of literacy or inability to access SMS due to poor connections could mean that some sections of the rural population may not be able to access early warnings. The use of speakers and radio which are accessible and use audio instead of text ensures that the largest number of people are warned in an efficient and effective manner (Climate Centre, 2019).

3.2.2. Cooperation

The Togolese Red Cross was able to cooperate with a variety of local and transnational civil society and public sector actors to set-up the mechanisms for the FbF FUNES system.

The Togolese Red Cross established a Preparedness Fund with seed money from the German Red Cross and the Federal German Foreign Ministry along with service-level agreements regarding the trigger and use of the funds. This ensured that civil society organisations which had a higher degree of local knowledge and needs had access to funding in times of need. This also ensured that funds were backed by a larger organisation with more financial resources than an NGO such as the German Foreign ministry. The service level agreement ensures that funds are utilised properly and reduces the chance of embezzlement or corruption in the distribution of funds, ensuring they reach beneficiaries in good form (Climate Centre, 2019; Kremers, 2022).

The Togolese Red Cross has a set of SOPs for each village located downstream for each risk-level which can be triggered ahead of a flooding possibility. These SOPs range from generic advice such as safeguarding documents to more specific information on evacuation points. The use of SOPs, rehearsals and drills ensure that local populations become familiar with preparedness measures and thus are more equipped to act more autonomously in the event of an actual flood risk. They further understand the risks they face and the preventative/mitigative nature of these actions (Climate Centre, 2019).

Based on output from the FUNES model, the Togolese Red Cross and the National Platform for Disaster Risk Reduction were able to plan and cooperate to release small amounts of water to avoid dam overflow while simultaneously preparing vulnerable downstream communities. Cooperation with the authorities in the national government as well as the dam ensured rapid flow of information to relevant local stakeholders and ease of monitoring the situation to adjust future actions and responses (Climate Centre, 2019).

3.2.3. Coordination

Coordination of data and other communication mechanisms ensured the success of this FUNES FbF system.

Data about dam flow level and gate operating hours are entered daily by operators from Communauté Electrique de Benin who manage the Nangbeto dam. This provides the FUNES with higher resolution data along with the automated data made available from water metres present upstream. This ensures a more accurate forecast of downstream flooding (Climate Centre, 2019; German Red Cross, 2022).

Flood impact data is collected, compiled and entered by the Togolese Red Cross annually during the high risk periods of the year. This ensures that more contextualised information from downstream communities are made available to the public sector as well as the FUNES system. Changing scenarios would necessitate updates in SOPS and this annual reporting method ensures that preparedness measures continue to remain relevant and potentially effective in the event of a flood (Climate Centre, 2019; Climate Centre, 2017b).

Data from public sector corporations, independent rain metres and civil society organisations is integrated in this model. By making use of multiple streams of data, the FUNES model is able to gain a more holistic picture of the flood situation and its possible impacts. Therefore, multiple stakeholders are integrated and incentivised to coordinate within the bounds of the system (Climate Centre, 2019).

The output from the FUNES model was able to accurately predict dam outflow leading to an automatic triggering to release funds to distribute cholera medication and mosquito nets by the Togolese Red Cross. This form of preventative preparedness has been able to reduce the impacts of downstream flooding substantially (Climate Centre, 2019).

3.3. Barriers, Expectations and Solutions

Despite the success of this FUNES FbF system, there are a few challenges that must be accounted for to further improve this best-practice.

The system requires close coordination with the public sector to ensure its use and implementation. An overburdened or weak public sector would impair such cooperation and thus negatively impact the implementation and utility of this system (Climate Centre, 2017a).

Initial SOPs may focus on only a small group of people who are limited to the 15 villages. The scope of the system requires expansion to better prove the utility of FbF in flood-risk management. This means that the scheme must be expanded to other dams or to more communities downstream to better test its utility and to alleviate disaster-risk in more population centres (Climate Centre, 2017a).

Success in FbF is contingent on the preparedness and capacities of involved institutions including the public sector, civil society organisations and local businesses. If the communication and cooperation mechanisms do not take off, then all stakeholders may not be able to improve preparedness capacities and may compete for scarce financial resources (Climate Centre, 2017a).

Transparency of funding mechanism and operation is required to create a scaled-up FbF system at a regional, national or international level. Scaling up could be challenging as more and more public and social sector actors will have to become involved in providing and raising funds for this system (Climate Centre, 2017a). Monitoring and revising of SOPs and long-term sources of funds are required to ensure the sustenance of this system (Climate Centre, 2019).

The reaction time frame for this kind of solution is short, requiring quick action to disburse funds and rapid action systems to be in place and to act in a timely manner. In the long-run, as the base risk of floods keeps rising, this may be insufficient to alleviate flood-risk. Further public sector support is required if such systems are to be scaled up to a national level (Climate Centre, 2017b)

Overall, it is noticeable how this kind of predictive and preventative preparedness effort has parallel effects on the community’s response and recovery. Firstly, the distribution of cholera medication and mosquito nets tend to be typical response and relief measures. However, by making use of the forecast, these measures can be taken pre-emptively to ensure the communities are better prepared for when the flood occurs. Finally, by improving preparedness and also response, the damage to the communities are reduced significantly which allows them to build back better and faster. These feedback loops will be discussed in the conclusions section.

VGI Mapping

Socio-technological Solution

Use of geolocation information from Twitter to monitor and map flooding in Jakarta

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description

• PetaJakarta makes use of Twitter to improve the information of flood impacts in Jakarta during rainy seasons

• Open-source softwares are used to compile, collate and verify inputted information

• The map is updated in realtime after information verification and displayed in a user-friendly website

(Holderness & Turpin, 2015)

Communication

• The verification is automatic to improve speed of verification and hasten information flows

• Data grant from Twitter allowed for the formation of an analytical model based on tweets from previous monsoon seasons

Cooperation

• People used as 'sensors' to gain locally contextualised flood

• Aggregation of information in a transparent manner allowing more actors to contribute to build the map

• Map data was sorted according to municipal boundaries. This allowed JEMA to better plan and coordinate response efforts

Coordination

•Affected individuals and neighbourhoods were able to develop a culture of self-help by requesting and providing relief supplied and informing stakeholders through Twitter

• Twitter was also used to communicate directly with pubic agencies for more serious emergencies, aiding in response prioritisation and efficiency

Challenges, Solutions & Scaling

• Data aggregation and analysis process is still relatively manual and requires more automation through the development of APIs

• The model may not be directly replicated outside of Indonesia as popular messaging applications may be different and thus some adjustments are required before best-practice emulation

•There is a feedback loop that parallely improves preparedness in at-risk communities. Recovery can also be enhanced by documenting weak points and following up with actions to reduce future risks of flooding

4. Response

4.1 Socio-technological solution

4.1.1. Background:

Jakarta sits along the coast of the Java Sea and is a major delta area with multiple rivers flowing through it from highlands in the South up to the coast. Around 40% of the city is located at or below sea level, necessitating complex hydrological arrangements to ensure the continued flow of water across the city area. Thus, around 72.7% of the region's population faces high levels of flood risk, with 10.2% facing extremely high flood risks, predominantly concentrated in the northern areas. Northern and Central Jakarta were found to be most vulnerable to flooding in a pan-Southeast Asia study (Holderness & Turpin, 2015; Sitinjak et al., 2018). Jakarta receives very heavy rainfall during the monsoon seasons. The annual precipitation in the city is expected to continue to rise with changing climate patterns which could potentially worsen the flood problems faced by Jakarta (Sitinjak et al., 2018)

Rapid population growth has led to a large number of residents in Jakarta to live in river banks and other floodplain regions at very high densities. This results in very few natural spaces and more impervious built-up areas which worsens flooding and causes subsidence which reduces the elevation of the land. Subsidence in Northern Jakarta is as high as 6cm per year (Sitinjak et al., 2018; Padawangi & Douglass, 2015).

Jakarta only has one-third of the green space it requires to be able to successfully drain a normal year's worth of precipitation. The densely settled land makes the expansion of these green areas difficult in the short and medium term (Padawangi & Douglass, 2015).

Patterns of land-ownership means that poorer populations are often concentrated in the Northern parts of the city and live in denser settlements and thus face substantially higher flood risks (Padawangi & Douglass, 2015).

The Peta Jakarta site was set up by the Jakarta Emergency Management Agency (JEMA) and Twitter along with the SMART Infrastructure Facility from the University of Wollongong in Australia. It was a platform that was able to coordinate various public, private and social sector stakeholders under a united banner improving the flood response substantially and empowered vulnerable actors (Holderness & Turpin, 2015).

4.1.2 Justification

The city of Jakarta and the JEMA has previously used community mapping through Open Street Maps. It has further been mandated to improve its outreach to residents through social media with rising mobile phone penetration in urban Indonesia. A ground up volunteer geographic information (VGI) mapping initiative would thus be useful and implementable with public sector support and social sector insights (Holderness & Turpin, 2015). The use of VGI allows local disaster management authorities in megacities to better coordinate their response and aid in rapid informed decision making while also allowing many in the city to be able to respond and contribute to flood response efforts. This is thus able to reduce the time needed between gathering information and then reacting to the floods, making responses more temporally relevant (Holderness & Turpin, 2015; Hidayat, 2020). Jakarta also faced 'lock-in' from its investment in structural measures. Thus non-structural measures that enhance adaptation of vulnerable communities to heightened flood risks can help Jakarta better manage flood-risks in the medium-term until long-run structural measures change (UNDRR, 2021).

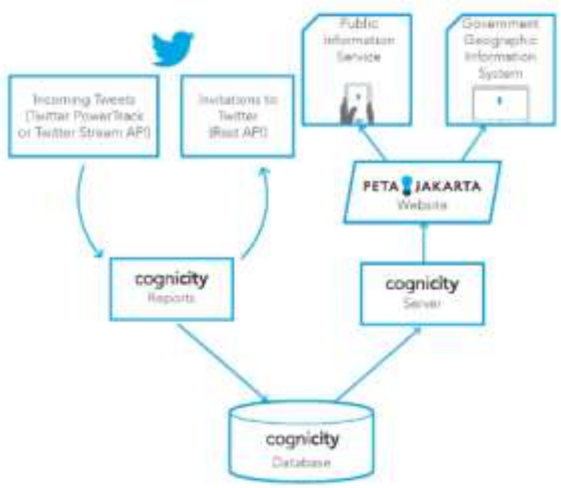
Jakarta has a high proportion of residents with access to a mobile phone. AN increasing number of these phones use the Global Navigation Satellite System (GNSS) to generate and store location data. Twitter is highly utilised among the local populace who account for 2.4% of all tweets produced globally (Holderness & Turpin, 2015; Fadmastuti, 2019). Open source software is free to use and can still be robust and of good quality. Paid software licences are often prohibitively expensive for use in the global South given public sector and NGO budget constraints (Holderness & Turpin, 2015). The knowledge of local contexts of Jakarta residents and first responders can form a dense map of high resolution collected and collated. This becomes a valuable source of information for risk management. This is heralded as collaborative governance where non-public stakeholders are involved as sources of information as well as decision makers in disasters such as floods by facilitating leadership and collaboration (Holderness & Turpin, 2015; Hidayat, 2020).

Southeast Asia is expected to be one of the worst affected regions from climate change. Local authorities are struggling to adapt due to the meagre resources available and the lack of reliable, historical information. Therefore, such an initiative which allows for the collation of useful information to inform response would be highly useful for public authorities and at-risk individuals to better respond to urban pluvial and fluvial floods (Holderness & Turpin, 2015).

4.1.3. Best-practice Description

Data on flood incidents are collected through the use of geolocation, tags and keywords on the Twitter platform which is extensively used by Jakarta's population. The collected data is managed by a free and open-source software known as CogniCity which acts as a framework to collect, collate and process urban data (Holderness & Turpin, 2015).

CogniCity is able to aggregate relevant VGI on Twitter using 'banjir' (flood) as a keyword to network more users through automatic invitations sent within 30 milliseconds. Every user in Jakarta who uses the word 'banjir' is automatically invited to join the reporting scheme to fill in and provide flood related data. It is able to transcend previous VGI initiatives such as Open Street Maps by allowing users to report flooding information in a more nuanced manner. Over 89,000 invitations were sent programmatically during the trials in 2015. The user only had to reply to confirm the authenticity of their report by text, provision of more information or through collecting photographic evidence (Holderness & Turpin, 2015).



[***Figure 11:*** *Architecture and Outline of CogniCity WorkFlow*]

The reports were then collated and published on a publicly available map on PetaJakarta.org. This information included geo-referenced locations to display the geographic distribution of the floods and related damages. The same information was made available to the JEMA and to the public to ensure transparency and easy coordination as they refer to the same data. The data was published on the website which was available in two forms: a desktop version and a mobile version (Holderness & Turpin, 2015).

[***Figure 12:*** *Series of messages on Twitter including unconfirmed report, verification request, verification and photographic evidence (Holderness & Turpin, 2015)*]

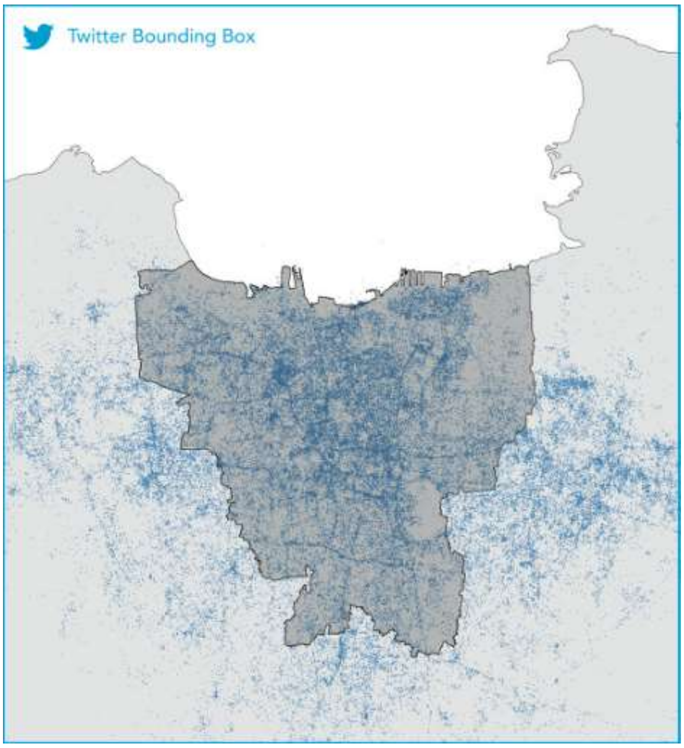
On the desktop version the map showed the entire Jakarta area with reports from the past one, three and six hours from each administrative division of the city in a choropleth (colour scale) map. The mobile version shows only the reports of the past hour with reference to the user's immediate vicinity. This is especially relevant given that 83.79% of users accessed the site through mobile phones compared to just 14.69% who accessed it through a personal computer system (desktop) (Holderness & Turpin, 2015; Hidayat, 2020).

[***Figure 13:*** *Local reports on mobile version (Holderness & Turpin, 2015)*]

The data processing was adapted to ensure scalability. The geo-location data was processed and collated on a central server. However, the rendering (formation and display) of the map was done on the user's device so that the server did not have to generate data intensive map tiles. This ensured that the server had sufficient capacity to process data on a real-time basis (Holderness & Turpin, 2015).

The PowerTrack API from Twitter was used as it was not subject to rate limiting (as seen in the publicly available version) as well as the fact that it can be used to filter keywords. However, the publicly available API was used to set up contact with potential users for verification purposes. This allowed the PetaJakarta team to filter out the noise in an efficient manner (Holderness & Turpin, 2015).

In addition to flood reports, a hydrological data layer was also available to optionally enable to track the flow of rivers, water pumps and other water infrastructure across the city (Holderness & Turpin, 2015).



[***Figure 14:*** *Density of Flood Related Tweets in Jakarta Metropolitan Area (Holderness & Turpin, 2015)*]

4.2. Evaluation

The PetaJakarta platform was able to successfully improve communication between a large group of heterogeneous stakeholders ranging from the JEMA, to the everyday citizen and other NGOs involved. The support of private firm Twitter further ensured the success of the platform. The spread of this platform to other Indonesian cities is a reflection of its success and utility as a flood-response mechanism.

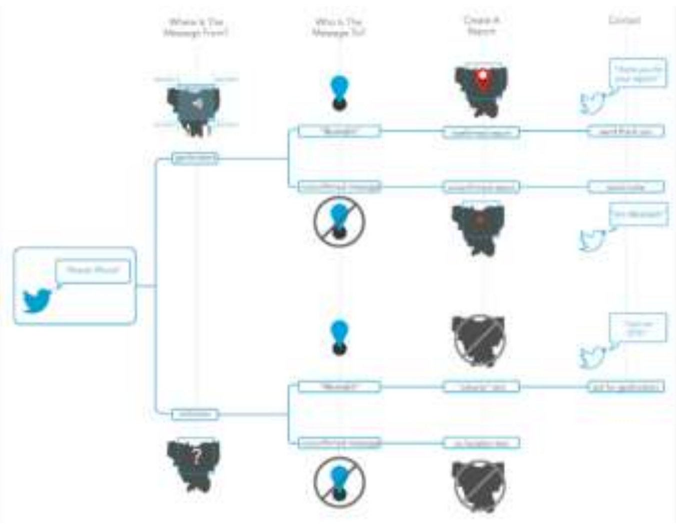
4.2.1. Communication

Pilots which were conducted 2014 were able to capture 150,000 tweets generated by 100,000 users over the course of 24 hours capturing key words such as *banjir* (floods), *tinggi* (high), *genangan* (pool) and *terendam* (submerged). Additionally around 3% of the tweets had precise geo-location information from the Twitter user. This aided in the quick identification of a pool of potentially relevant tweets by the PetaJakarta team (Holderness & Turpin, 2015).

Twitter provided a data grant which allowed CogniCity and Peta Jakarta to access previously archived tweets from previous years' monsoons. This allowed them to analyse key patterns and better design the real-time system for use in the next monsoon period. Twitter's use as a short messaging communication and broadcast tool aided in catalysing the flow of information between various social and public sector users on the platform (Holderness & Turpin, 2015).

Verification of information is crucial to ensure the relevance of crowd source data and its authenticity. Manual verification is too labour and time intensive. Machine learning was used to process and verify the authenticity of the large data volume prior to any manual checks (Holderness & Turpin, 2015).

The difference in the web and mobile versions ensured that user's were only able to access relevant data based on Tobler's law that only data from the close geographic vicinity that is recent becomes relevant to the user. Thus, the use of the spatio-temporal filter ensured actionable data that did not overwhelm the user with unnecessary reported information. This also improved communication by streamlining data to suit the needs of the user and improve its relevance and its actionability (Holderness & Turpin, 2015).



[***Figure 15:*** *Overview of data management process of CogniCity and Twitter (Holderness & Turpin, 2015)*]

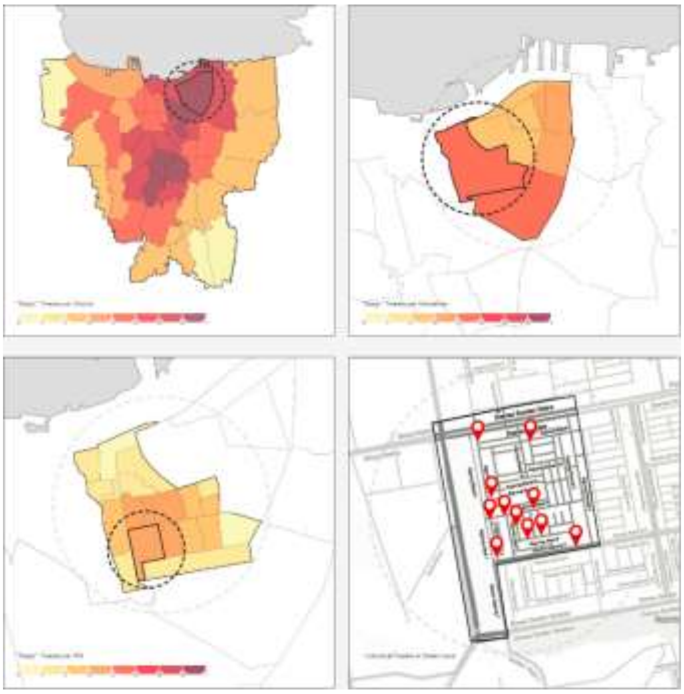
4.2.2. Cooperation

The Peta Jakarta site is able to make use of open-source software and commonly found mobile devices to collate and present information that can be easily interpreted and acted upon. Open source softwares allowed for higher transparency of how data was processed and also ensured more actors could contribute to the platform as software licences were not required. This is especially important in a situation where public, private and social actors may not be able to afford professional softwares with paid licences (Holderness & Turpin, 2015).

To confirm the actual extent of the floods, people were used as sensors to verify the flooding damage. This was done through the CogniCity software where locals in the surrounding area of concern were invited to confirm the data. This verification was immediately updated onto a publicly available map. Verification provisions were relatively straightforward as it simply involved confirming and providing geographic and photographic information (Holderness & Turpin, 2015).

Given the use of open-source software and the processing of large volumes of data from individuals' devices, privacy becomes a possible concern. To respect the privacy of the user, all user identities were anonymised before storing data. Additionally, only user data where the user had replied to the verification was stored for rendering the map (Holderness & Turpin, 2015).

Data was made available and sorted through municipal administrative scales of various levels for ease of use by the JEMA. This included the municipality, sub-district, village and neighbourhood levels. By doing so, the platform was of even higher utility and was easier to use for JEMA to match with their internal documentation. This ensured that less time was spent on administrative matters and more resources and manpower could be diverted to rescue and recovery operations (Holderness & Turpin, 2015).



[***Figure 16:*** *Choropleth map of flood reports at various municipal scales (Holderness & Turpin, 2015)*]

The above reporting information improved the resolution of the information from a 6 hour interval to an hourly interval. The higher resolution of data allowed the public sector to respond in a more nuanced manner as they now had better knowledge of the ground situation (Hidayat, 2020).

4.2.3. Coordination

A large number of stakeholders were able to coordinate in a smooth manner using the Peta Jakarta platform. This mechanism simplified the information sharing process and enhanced the response abilities of involved stakeholders.

The validated and actionable information allows residents to take resilience measures or to evacuate ahead of time and also allows authorities to finetune their response plans to the situation on ground. This encouraged the maintenance of the mutual self-help culture of '*Goyong Rotong*' among residents by digitising information and making access easier. This is due to the democratisation of the information generation and response process where residents are not limited by top-down governance structures, thereby empowering them to take action in their own hands and emerge significantly more resilient (Holderness & Turpin, 2015; Fadmastuti, 2019).

[***Figure 17:*** *Message sent by Social Services Agency on Twitter and PetaJakarta (Holderness & Turpin, 2015)*]

Given the same data sets are used by residents and the government, the solution brings in a sense of civic co-management of the flooding thereby integrating two different stakeholders under the same banner. This allowed for faster and more effective response measures to be taken by the JEMA as well as by residents (Holderness & Turpin, 2015).

The mechanism of self-reporting became self-evolving over time. People were able to use the report feature on Twitter to provide information on floods and engage with other members of society as well as the local government (Holderness & Turpin, 2015).

The website was designed to ensure ease of access and understanding. This included balck and white backgrounds with information highlighted in bright colours for ease of navigation. The default language was Bahasa Indonesia which is commonly spoken in the region and ensured its accessibility. Ease of accessibility of information further democratised the response process and empowered previously less involved individuals in response missions (Holderness & Turpin, 2015).

Those people without access to mobile phones were still able to send useful information without photographs through the help of other individuals. Thus SMS was used in addition to twitter and typically contained the street name and municipality information to identify the location. The Twitter platform was also used by public agencies such as the Social Services Agency to inform nearby residents of the provision of relief supplies such as food or of evacuations being conducted (Holderness & Turpin, 2015). Transparency of data management processes ensured that the PetaJakarta project was sustainable and ensured easy integration of newer stakeholders (Fadmastuti, 2019).

4.3. Barriers, Expectations and Solutions

Despite the high level of stakeholder integration in this best-practice, many new challenges were raised over time.

Verification of reports can still be a challenge, as often despite machine assistance, it is a somewhat manual process and can be time consuming making it difficult to generate data for flash flooding. This is particularly important given that Jakarta is at high risk of flash floods caused by heavy rainfall events (Holderness & Turpin, 2015).

Public agents require training to be convinced of the utility of VGI and its reliability. They also need to be trained to learn how to interpret and make use of the data to manage flood response. The training needs to be conducted by data experts to ensure proper transfer of knowledge. (Holderness & Turpin, 2015).

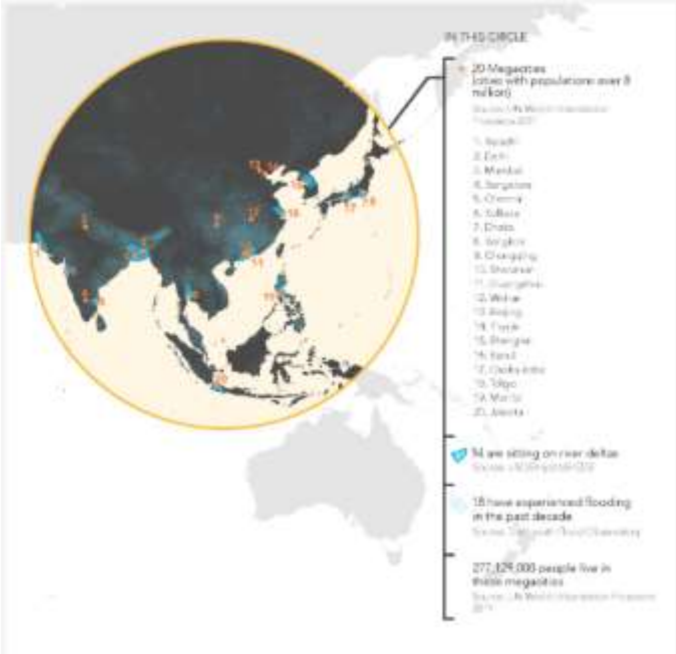
Decision support matrices must be developed to guide actions and responses based on data to ensure better flood response outcome. While VGI is useful, its utility could potentially improve if combined with other data sources such as SUAV surveillance or LiDAR analysis. Hence, APIs must be developed to better integrate these data sources for use by public agencies. There is a potential for this to be used as a preparedness/mitigation mechanism. Location based alerting may be useful, however APIs and mechanisms still need to be developed. APIs could be developed by Twitter to better support the PetaJakarta platform, or the costs of development can be split between the government and Twitter (Holderness & Turpin, 2015).

While Twitter was useful in Jakarta, multiple social media platforms may need to be integrated in other cities , especially in those with a lower smartphone penetration rate. Therefore, the transferability of the model or practice as it is is challenging, but could be adapted for other applications such as WhatsApp in other cities (Holderness & Turpin, 2015).

Local level coordination cannot be easily conducted on Twitter. Instead a different application such as WhatsApp had to be used to conduct a rapid-needs assessment and to respond to that within a local and JEMA level to avoid too much unnecessary tweeting. Thus, integrating these aspects into the PetaJakarta platform will be essential to better centralise and streamline reponses. A careful distribution of shared responsibility is needed to ensure that no particular stakeholder is overly pressured or extended during a flood event (Sitinjak et al., 2018).

Flooding in Jakarta is a compound problem that involves general water management as a whole including access to clean water and maintenance of water infrastructure across the city and the surrounding urbanised areas. Response mechanisms cannot act as a panacea to flooding issues but are a crucial part of a greater whole (Padawangi & Douglass, 2015).

PetaJakarta has been renamed as PetaBencana and has been implemented and expanded to other Indonesian cities. Furthermore there is a lack of integration of the private sector in the PetaBencana initiative with the exception of Twitter. Greater private involvement could be used to crowdfund systemic improvements such as the expansion of servers to allow the site to host more users and to expand the scheme to cities such as Bandung and Semarang which are also vulnerable to floods (Hidayat, 2020).



[***Figure 18:*** *List of Major Megacities in Asia with those in deltas highlighted (Holderness & Turpin, 2015)*]

Cash Transfer Systems

Socio-technological Solution

Use of mobile SMS and vouchers for rapid cash transfer

Prevention | Mitigation | Prepardness | Response | Recovery

Best-practice description

• Dan Church Aid coordinated with the Cambodian Government and WING bank to set up cash collection points for flood affected rural residents

• Those with mobile phones were sent a unique 8-digit code that could be shown at a cash point to collect the cash

• Those without mobile phones received vouchers which could be exchanged for cash

Communication

• NGOs conducted workshops to ensure beneficiaries understood how cash scheme worked

• Humansis software was used to coordinate data sets collected on site and from the governmental IDPoor database quickly and without much technical training for the user

Cooperation

• Lists of beneficiaries were publicly available and villagers could request their inclusion

• Access to information in a transparent manner ensured that the parallel governmental cash programme also reached beneficiaries

• 100% of beneficiaries were able to receive the cash

Coordination

• Isolated members or those who did not cash their voucher were assisted by the village chief to ensure no one was left out

• Most of the cash transfer was used for food, condiments and medicine. However, some individuals invested in housing repair or in chickens or improvements to their livelihoods

Challenges, Solutions & Scaling

• There is usually a lack of trust between governmental and social actors. This may inhibit potentially useful collaborations that could improve this scheme in the long-term

• There is a possibility to coordinate with other financial civil society institutions such as savings organisations to better plan recovery measures and include vulnerable members

• There is a feedback loop that parallely improves preparedness, mitigation, response or recovery depending on how the cash is used. Anticipatory cash distribution may be useful in the future.

5. Recovery

5.1 Socio-technological solution
5.1.1. Background

Severe floods had occurred inCambodia in September and October of 2020 had displaced approximately 11,000 families according to the National Committee of Disaster Management. The estimated death toll was 36 individuals (Narim, 2020). Overall, around 2 million people were exposed to flood-risks of which 800,000 were directly affected by the inundation. 175,872 households were seriously affected by flooding across 14 provinces (Cambodian Humanitarian Response Forum [CHRF], 2020; Gally, 2021). An estimated 388,000 individuals were receiving assistance under the IDPoor scheme and the Royal Cambodian government had released around 12,000 MT of rice as food aid (CHRF, 2020). Over 100,000 houses and 707 school buildings were damaged across 19 provinces of Cambodia (Narim, 2020).

[***Figure 19:*** *Map of Cambodian Provinces Affected by FLooding in 2020 (CHRF, 2020)*]

Around 230,000 hectares of paddy (rice), the main staple for the region and 80,000 hectares of other crops were inundated and damaged. Much of this damage occurred in the Banteay Meanchey, Battambang, Phnom Phen, Pursat and Pailin provinces. Overall, 329,000 hectares had been damaged (Narim, 2020; CHRF, 2020).

Despite response from multiple agencies, many families often lacked access to basic items such as soap and mosquito nets (for sanitations and health purposes) and required assistance to gradually rebuild their livelihoods rather than just receive food assistance alone (CHRF, 2020). The CHRF requested funding of US$ 9.14 million to fund all its proposed humanitarian activities ranging from food assistance, child protection, sanitation to general health and education. Cash transfers initiated by local NGOs were a major part of this scheme to assist with recovery (CHRF, 2020; Chea, 2022).

Under the food scheme, both immediate cash transfer for procuring specific nutritional items as well as follow-up cash transfers for special needs groups were proposed (CHRF, 2020). Floods hit the poorest harder as they immediately lose their source of income and also lack any savings to fall back on in lean times. Cash assistance becomes the most useful way for them to stay afloat (Chea, 2022).

5.1.2 Justification

Cash transfers are predominantly used on securing food and water. This means that fewer families or individuals at risk or affected by floods are likely to go a day without food.Cash transfers are notably more beneficial to those living in more isolated areas and unable to access other forms of relief or recovery aid. As cash is the most common medium of value in the global South, it is easier to distribute and spend (World Food Programme, 2021). Families were less likely to go into debt or take other loans for securing food or repairing housing when provided with cash transfers. This ensured that even if families cannot build back better, they can at least bounce back to the same state quickly and in a financially viable manner. The above factors also reduce the associated stress and anxiety that comes along with managing the consequences of flooding (Gros et al., 2019).

5.1.3. Best-practice Description

NGOs such as People in Need and Dan Church Aid were able to make US$ 20,000 in cash transfers to over 500 families in the Siem Reap and Battambang provinces in Cambodia which were affected by floods. Every single eligible family or household received US$ 43 which assisted them in sustaining their livelihoods and were easily accessed through a financial service provider WING bank in a transparent manner (Narim, 2020).

This form of cash-transfer to aid recovery has been used in other areas in Cambodia as well for non-flood related disasters. The intention is to ease the short-term and medium-term impacts of flooding (Gally, 2021). Cash transfers can aid the recovery process by alleviating financial pressure that coud lead to negaitve coping strategies such as child labour (Dan Church Aid, 2021).

Dan Church Aid provided cash vouchers to 2,482 beneficiaries in four provinces: Siem Reap, Battambang, Pursat and Kampong Speu through cash vouchers using WING as the primary financial service provider in 2020. Funding for the cash vouchers came from the Danish International Development Agency's Emergency Response Fund (Dan Church Aid, 2021; Gally, 2021). The Beneficiary Management System (BMS) was used to ensure transparent real-time data availability to various stakeholders involved in the cash transfer process. This was followed in Siem Reap and Battambang. Beneficiaries received an SMS alert with a unique 8-digit code. This code could be taken to the WING bank to receive the cash transfer. This method has 845 beneficiaries (Dan Church Aid, 2021).

The platform was known as Humansis, and cash reached around 80% of beneficiaries in 4 days and 100% of all beneficiaries in 8 days. Humansis is an open-source beneficiary information management system that can streamline aid and cash transfer delivery (Dan Church Aid, 2021; Gally, 2021).

The second non-technical system used was the centralised distribution of cash vouchers which could be exchanged for cash in Kampong Speu and Pursat. Physical cash was arranged for by the WING agent through a pre-established contract. Distribution occurred through a strategically held 'ceremony' to maximise attendance by beneficiaries (Dan Church Aid, 2021; Gally, 2021). The WING distribution point was able to check if any beneficiary failed to cash the voucher and followed up to personally assist ensuring the inclusion of anyone who was confused with the system (Dan Church Aid, 2021)

[***Figure 20:*** *WING Cash Distribution Point (Legarta, 2021)*]

5.2. Evaluation

5.2.1. Communication

The social sector can inform the public sector to better design the mechanics of a cash transfer. By having a more intimate knowledge of the communities on ground, the social sector can always inform the government if making use of SMS codes for mobile cash transfers is the best solution to implement a governmental cash transfer scheme. The cash transfer scheme was able to improve communication with local governments to complement the provision of cash assistance through the IDPoor scheme (Dan Church Aid, 2021).

Given the more technical nature of the government official's knowledge and approach to cash transfers, NGOs were able to bridge communication gaps by better explaining to beneficiaries how cash transfers functioned and how they could access cash in a more understandable manner. This permitted a larger number of beneficiaries to be able to independently be able to collect cash (Dan Church Aid, 2021).

Around 97% beneficiaries received training on how to receive cash assistance from the local NGOs and Dan Church Aid. The other 3% were personally followed-up with by the village chief to ensure their ability to receive cash. Overall, 100% of beneficiaries were advised to keep their phone on and charged at all times. Only 87% were able to do so in practice. The remaining 13% were unable to do so because of the lack of electricity in some areas while others had to work long hours in the field where they also were less likely to receive a signal. By personally engaging beneficiaries and through careful training, NGOs were able to better communicate with at-risk populations and facilitate follow-through in aid provision and collection (Gally, 2021).

5.2.2. Cooperation

Cash transfers are made use of by both governmental and non-governmental organisations to assist with general disaster recovery in Cambodia. At the local level in villaged, Dan Church Aid partnered with smaller, local NGOs and village chiefs who had a more intimate knowledge of the region and the people. Individuals who believed they qualified for cash assistance could reach out to the NGOs to request their inclusion as listed beneficiaries were publicly available for individuals to check at a local level. Beneficiaries were given a 48 hours window where beneficiary lists were published and they could be added. Initially around 2,400 beneficiaries were identified and only an additional 10 were added through appeals or complaints. Local authorities recognise how this helped avoid conflicts or exclusion post the distribution of cash (Dan Church Aid, 2021; Gally, 2021).

Government corruption was placed in check by using openly available beneficiary data to cross-check if beneficiaries are receiving transfers. This improved the cash transfer outreach. The misuse of funds is a major concern in cash transfer programmes. However, the transparency of information and conduct in this case ensured that such situations did not occur and that cash reached those who were slated to receive it (Dan Church Aid, 2021). Cooperation with WING bank to set-up temporary cash withdrawal stalls in convenient and reachable areas. 100% of beneficiaries in all 4 provinces were able to easily reach the withdrawal point although occasionally motorbikes were stuck in the mud. Overall, they also felt safe queueing up to cash their vouchers/SMS codes. The retrieval of the cash through SMS or vouchers saw overwhelmingly positive reviews from the local stakeholders with no registered complaints about the mechanism (Gally, 2021).

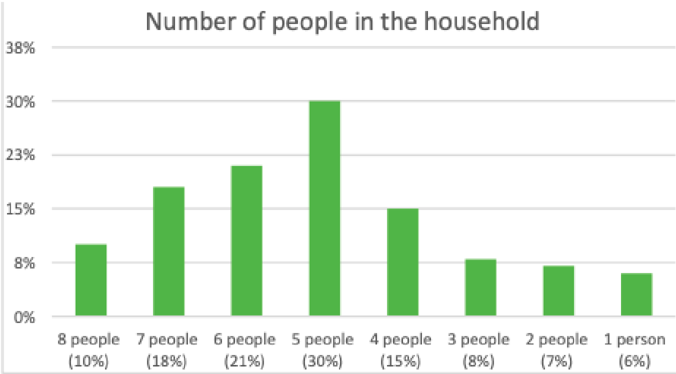
Humansis was able to pull data from government databases to help aid workers cross-check beneficiary details and to avoid corruption. It was additionally used to input newer data and could function in areas of low connectivity, simplifying the data management process compared to using spreadsheets. This ensured greater efficiency in management of the cash flow and distribution and made it easier for NGO personnel to coordinate with WING to avoid confusion and errors (Lergarta, 2021).

5.2.3. Coordination

Cash transfers allowed 100% of beneficiaries to best make use of it to suit their unique needs. Some families used it to procure more food supplies while others bought more sanitation equipment or educational expenses. Each household was able to use funds as they saw fit to optimally recover from the flood (Dan Church Aid, 2021). Around 46% of households saw rice procurement as their primary priority in using cash assistance which complements the IDPoor programme from the Cambodian Government. However, 37% used the cash to buy medicines, 7% food seasonings, 6% school supplies and another 3% invested in their crops. Families which benefited from either the IDPoor programme, the cash transfer programme or others had sufficient food stocks to last them over the next 4 to 6 weeks (Gally, 2021).

The village chief played an important role in gathering the general public and personally following-up with struggling beneficiaries. This ensured that no beneficiary was left behind and that the cash transfer reached the relevant person. Despite the use of technology in this situation, occasionally a human touch and face to face engagement ensured inclusivity of all vulnerable and affected individuals (Gally, 2021).

Around 17% of beneficiaries received government support for food. This could be a reason as to why many of them spent their cash on non-food items. Government assistance provided rice, dried noodles, canned fish, fish sauce, soy sauce, sugar and salt. However, none of the beneficiaries received cash assistance from elsewhere. Relatively uncovered populations were assisted through this programme. The use of SOPs at every stage of the programme reduced the chance of confusions and resultant errors. The transparency of procedures ensured all involved stakeholders felt safe (Gally, 2021).



[***Figure 21:*** *Number of people per household in Cambodia (Gally, 2021)*]

[***Figure 22:*** *Distribution of cash assistance utilisation by category in Cambodia (Gally, 2021)*]

Cash based assistance allowed individuals to respond to floods by securing food and medicine. However, some beneficiaries were able to use the funds to assist with the recovery of their business/farms. Thus an investment in recovery measures and aiding resilience on an individual basis was observable indicating the success of the scheme (Chea, 2022).

5.3. Barriers, Expectations and Solutions

Despite the efficiency and inclusivity with which the cash transfer programme had worked in Cambodia, there are some important factors to consider prior to implementing a similar scheme. Cash transfer programmes can become siloed across different stakeholder groups. Often the public sector and NGOs parallely run cash-transfer schemes with similar objectives and fail to coordinate with each other. Often, there is no standardised procedure to follow in the implementation of the schemes between the public and social sectors leading to disorganisation and confusion (Dan Church Aid, 2021).

A lack of mutual trust between the government and civil society organisations can potentially hinder coordination and possible synergy for better delivery of cash transfers. The formation of two-way dialogues in this regard to address the mistrust as well as to form transparent SOPs may be required to improve the programme in the long-term. The Ministry of Economy and Finance of Cambodia has opened up a dialogue with NGOs to link cash transfer schemes, local capacities and social protection to engage in a more prevention-based approach (Dan Church Aid, 2021).

Partnering with other social organisations such as saving schemes and women's groups could improve the outcomes of cash use by women who are outside this support system who have received cash transfers. Thus, engagement of other financial civil society institutions and instruments may allow for a more financially resilient community in rural Cambodia that can quickly invest cash in recovering from flooding.

Cash transfer programs require at least a 48 hour period for the participating financial service provider to set up the distribution point. Using fully mobile systems might hasten the pace of cash transfer programmes if the infrastructure is adapted at a local level (DCA, 2021).

Best-practices onsite were recorded. Additionally, 15% of beneficiaries were surveyed as a representative sample to generate feedback and recommendations to improve the programme in the future. Close-ended questionnaires were used to engage and receive feedback from villagers and to assure that constructive feedback will not have negative consequences. Open-ended interviews were used to better discuss issues and relay it to public sector stakeholders. Use of physical distribution points was difficult for around 5% of beneficiaries due to poor road conditions. Elderly people were more likely to change their numbers or were unable to make use of the SMS systems due to illiteracy or lack of knowledge on operating the phone. To alleviate this, the NGO noted down the phone number and withdrew and provided the cash to the eldelry beneficiary. Occasionally, non-beneficiaries stood in line on behalf of beneficiaries. There is a chance that it could be done to cheat the system. A cross-checking system could be implemented for the future (Gally, 2021).

From the above case study, multiple feedback loops were visible. Firstly, the cash transfer scheme could be considered partly as a response scheme as it runs on a short time frame and is somewhat reactionary. Thus, there is a parallel investment in response and recovery measures. Additionally, some of this cash funds were used to buy medicines and other smaller items which may be of use for the next flooding season. This is especially the case with medication which may be in short supply during a flood event. This therefore also has positive effects on preparedness among households. Finally, some individuals used the cash to invest in more resilient farms or improvements to their home which could better withstand floods in the future. This therefore, becomes a possible form of mitigation. Thus, it is observable that depending on the utilisation of the cash, parallel effects on other stages of the disaster management cycle can be seen.

Society Best-Practices Discussion

Expectations:

In general, compared to the private and public sectors, civil society organisations are able to bridge communication gaps with local actors and the average citizen. Given that most civil society organisations have a local focus and have access to local networks to convene resources, they are in a position to transform disaster-risk management approaches from a top-down to a bottom-up paradigm. The knowledge of local networks allows them to contextualise the impact of flood-risk to at-risk populations and transcend technical jargon from the public and private sectors to raise awareness. This gives them a unique leverage in flood-risk management by reducing the pressure on the public sector in risk management by supplementing efforts and assisting with non-structural measure implementation (PUB01, 2022; SOC01, 2022; PAP01, 2022).

A good example of such efforts is visible in Mozambique. While private firms like HKV worked in tandem with local disaster management authorities and the Dutch government to plan and implement a variety of non-structural and structural measures, there was a clear dependence on local NGOs to garner local support. NGOs acted as a forum through which technically-oriented actors were able to consult non-technical actors and integrate their concerns and advice in the planning and execution of measures. Furthermore, there is an expectation of NGOs to raise awareness of flood risks among local populations. For the HKV and Dutch DRR Team consultations in Mozambique, local NGOs painted murals on walls to remind the public of the severity of flooding and encourage them to prepare better for future flood risks (PAP02, 2022).

With respect to the case discussed in the paper, the use of wall paintings by the Environmentalist Foundation of India is also of interest. The wall paintings were created by the NGO in collaboration with the local residents around Madambakkam lake, particularly younger volunteers. The messages were often along the lines of highlighting the importance of the water body and the need to preserve its ecological and hydrological functions. This education also ensured that more residents were inspired to take action and involved in the long-term preservation of the lake. However, no such education effort appeared to have been taken by the Greater Chennai Corporation or the Sun TV Network who had funded the restoration. As such they were only technical and financial actors, although they both have potential to also be social actors. The social aspects of water body restoration fell largely under the EFI's purview (EFI, 2021b).

The social sector is particularly crucial in supplementing the preparedness and response efforts undertaken by the public sector. This is often because most public sector disaster response teams are typically national organisations which may not be able to efficiently orient themselves to local contexts. As raised in one of the interviews conducted with a civil society member, NGOs and individual civil society members typically assisted disaster response forces. During the severe flooding of Chennai city in 2015, the interviewed civil society members coordinated and assisted the evacuation of neighbouring apartment buildings as the National Disaster Response Force was less familiar with the local terrain and landmarks. While the evacuations may have succeeded without local support, the social role that civil society members played ensured that evacuations were successful and that the needs of the evacuees were taken care of upon evacuation (SOC01, 2022).

NGOs play an important role in bringing attention to areas where urgent action is required. This is especially true of NGOs with an environmental focus. More often than not, the large size of government bodies may make focussing and keeping track of localised risks a huge managerial and administrative challenge. This often leads to certain areas of flood-risk getting neglected due to a lack of investment in structural and non-structural measures to alleviate risks and improve resilience. The social sector in the form of residents' associations and NGOs, particularly those which have environmental or civic interests are able to raise such issues to the public sector, formally requesting interventions. Within the cases discussed above, the EFI had to raise the issue of the Madambakkam lake to the Public Works Department prior to any intervention. If not, it was falling into a state of disrepair.

Barriers:

The social sector faces many barriers in its efforts to operate projects that can alleviate flood-risks. Currently, social media tools are made use of during a disaster to coordinate response. However, this does not aid mitigation or preparedness in a post-disaster paradigm, where the tool is not used for planning purposes (SOC01, 2022). Considering the PetaJakarta projects, the use of social media did indeed improve the coordination of response efforts by the emergency forces, however, the damage caused by the floods were still relatively high and no long-term non-structural measures were taken to reduce the risks of flooding in the future (Holderness & Turpin, 2015). Similarly, WhatsApp as a tool for communication was used predominantly only during the Chennai floods to coordinate response efforts. “Instead of doing something during an emergency, it is best all are connected through Social media & the reach should be in such a way that everybody is benefitted” (SOC01, 2022, p. 1). Thus, there is a need to move to a pre-disaster paradigm where social media tools such as Telegram and WhatsApp are made use of to coordinate mitigative measures and improve preparedness in local areas, rather than reacting to floods.

There seems to be a lack of mutual trust between the public sector, which is usually responsible for water and flood governance, and NGOs, especially in the global South. This can limit potential collaborations which may improve the execution and design of various structural and non-structural measures. This is particularly problematic in states with a more top-down approach to flood management such as Myanmar, where consultations for improving flood-management systems were largely kept within the technical authorities such as the hydrology department, disaster management offices, HKV (private sector consultant firm) and the Dutch DRR Team. The communication with the local population was only to a modest extent, and thus the utility and impacts of the measures proposed ran the risk of being understudies. Especially the socio-economic and resilience impacts on vulnerable and lower income river-side communities (PUB01, 2022; PAP02, 2022).

NGO initiatives are highly dependent on charity and aid agencies for funding various non-structural and structural measures. This means that funding availability is often scant as well as volatile and is oriented towards flood response rather than mitigative measures (SOC01, 2022). This means that the spending on managing and recovering from flood damage gets prioritised due to its urgency which may be more expensive in the long-term than investment in mitigative measures. As seen in the above cases, funding for cash transfer initiatives as seen in Cambodia were much more easily available and quickly disbursed by the Danish aid agency. However, the forecast-based finance initiative in Togo which improves preparedness has not been replicated as much as the cash transfer programmes. Thus, the social sector seems to be trapped in a disaster response dominant paradigm.

NGOs and civil society tend to be the least technically oriented and thus struggle with gathering and handling quantitative data to argue the value of interventions that they demand from the public sector. This is a compound challenge given that the public sector, which is usually the biggest stakeholder and actor, tends to have a culture of favouring the technical and the structural over the social and the non-structural data (PAP01, 2022).

<u>Feedback Loops:</u>

Over the course of the five case studies, various feedback loops were observed. While they were highlighted in the respective case studies, their general implications were left undiscussed. The following section will expound more detail about these feedback loops.

Firstly, it appears that an increased investment in structural and non-structural measures which are preventative or mitigative in nature ensured a better recovery after a flood event. This is because firstly, a preventative measure directly aids in reducing flood-risks by reducing the probability of a flood occurring in the first place and thus reduces the flood-risks. Mitigative measures improve the resilience of the area by ensuring that it can take a higher level of flood damage than before. By being better protected, the damage caused by the same severity of flooding is significantly reduced if a mitigative measure is taken than when mitigation is ignored entirely. The reduced level of damage requires fewer human and financial resources to repair and return to the old normal or to bounce forward to a new normal. Thus the combined effect of reduced probabilities of flood occurrence and magnitude of damage if a flood occurs, allows greater investments in recovery.

Bringing in the case study, the lake restorations in Chennai are an example of a combined preventative and mitigative measure. The restoration and preservation of the lake entirely prevents the chance of pluvial flooding from occurring in the event of a normal monsoon by improving percolation to the aquifers underground and storing the rain water. However, it is also a mitigative measure as the structural reinforcements and deepening of the lake bed ensured that in the case of an unusually voluminous spell of rain, the excessive stormwater had a place to accumulate outside of housing estates and public transport networks. In doing so, the same structural measure thus reduces the damages faced by nearby housing and transport infrastructure. Additionally, the roping in of local volunteers ensured that there was a non-structural measure in place to safeguard the functionality and maintenance of the structural measure (lake restoration). Thus, the region around the lake is likely to recover much faster and better due to this effort (EFI, 2022).

The next major feedback loop seen was the parallel effects that an investment in recovery can have on the mitigation, preparedness and response stages. The investment in recovery raises societal resilience to flooding. When there are higher levels of resilience, local residents are able to reduce their risk of damage from flooding events thereby mitigating some flood-risks. Additionally, locals may be able to divert some resources to aid in preparedness measures that further reduce the flood-risk by reducing the vulnerability of local residents. Finally, given that fewer resources are required to recover from lower levels of damage and that a smaller proportion of the population would be vulnerable or the overall degree of vulnerability is reduced, response resources can better prioritise the most vulnerable.

This unique feedback loop can be observed in the cash transfer scheme in Cambodia. In general, depending on how the scheme is implemented and how funding is used, it could improve flood resilience across any of these stages. The cash transfer was used by some families to buy additional food products. This ensured that they were fed and is thus a form of flood response. However, less vulnerable families were able to invest in their businesses thereby making them more resilient for future flood events and thus appears to be a recovery or mitigative measure. Finally, some families also bought some medical supplies they could have on hand if required and thus constituted a preparedness measure. (Dan Church Aid, 2021).

The third feedback loop identified was the effect of preparedness on response and mitigation. Improved preparedness naturally improves response as the reduced vulnerability allows response forces to prioritise the most affected. However, improved preparedness also allows for mitigation of flood damages from an everyday perspective. This means that while infrastructure may still get damaged, the potential damage could be reduced through a preparedness measure.

Connecting back to the discussed case study, both these loops can be observed in the use of the FUNES system to mitigate fluvial flooding in Togo. Firstly, the use of a predictive flood estimation system along with a locally appropriate early-warning system ensured the populations downstream were prepared to evacuate incase of a flood. This thereby reduced the vulnerabilities of the downstream populations who were able to respond better to floods by procuring cholera medication and mosquito nets to safeguard their health. However, the same measure was also able to make use of predictive modelling to release small amounts of water from the dam in a timed manner. This ensured that the severity of the flooding downstream was reduced which impacted fewer key infrastructure installations and housing. This therefore appears to be a mitigative measure (UCF, n.d.; Climate Centre, 2019).

The final feedback loop observed was the effect of response on preparedness and recovery. Improved response ensures that the most vulnerable are protected and thus are able to recover faster. However, better response in one area can trigger better preparedness in nearby vulnerable regions. This is particularly visible with the use of volunteer geographic data in Jakarta.

The PetaJakarta initiative allowed the local emergency response force to gain a better understanding of flooding extent and its evolution to adjust their response. However, the availability of photographic evidence on an easy to access site ensured that many residents who were in nearby areas were able to evacuate in advance or better prepare themselves for the event of the flood entering their district/neighbourhood. This therefore improves preparedness in areas where the flood was yet to enter. Finally, the improved response and preparedness ensured that the communities were able to recover faster from the pluvial floods as they faced fewer damages from the flood(Holderness & Turpin, 2015).

Emerging Solutions:

Despite the above outlined challenges, there is space for hope in reforming the social sector and improving resilience for all stakeholders, especially the most vulnerable individuals.

Social media applications such as Twitter and WhatsApp have allowed civil society organisations to rope in more individual actors in relief efforts by democratising the data generation and follow-up action processes. This empowers a larger section of society to mobilise resources (SOC01, 2022). This democratisation of data gathering is best visible in the PetaJakarta initiative. By allowing the generation of contextualised flood data aggregated on a publicly available map, emergency response forces and residents could coordinate and mobilise resources more efficiently. However in addition to that, the use of free and open-source softwares to develop the platform ensured the rapid replication of the initiative in other cities in Indonesia. This allows for flattening top-down oriented hierarchies and ensuring a whole of society resilience and can transform the underlying vulnerabilities and circumvent governmental oppression and pressures (PVT01, 2022).

The above also goes hand in hand with the increased presence of VGI and participatory mapping. This allows civil society to enter into an active two-way relationship with other more technically oriented stakeholders and transcends traditional economic and commercial paradigms of value.This comes because of the additional transparency and cohesion it gives the diverse civil society sector (PVT01).

The anticipatory spread of information is increasingly being studied and utilised to drive pre-disaster mitigation and preparedness measures. This is seen on various media ranging from modern social media applications to radios and SMS. Radio in particular proved to be a useful medium through which preparedness measures and early warning messages were related to downstream residents. This allowed the villagers to take charge of the situation and mobilise themselves without a high degree of external assistance. Twitter in PetaJakarta played a similar role in providing anticipatory information for those who had not yet been affected by floods. This has allowed the vulnerable to be significantly more empowered and able to take charge of managing floods than before. However, a more formal and established adoption of anticipatory information systems is required by coordinating with the public sector, to ensure the largest number of vulnerable populations can be notified (SOC01, 2022).

Multi-stakeholder involvement driven by local residents improves the trust between public and social sectors as residents are able to hold both parties accountable. This provision of power is crucial as it ensures that bottom-up approaches to disaster management are successful. One mechanism of how this can be achieved is through transparency. By publishing the list of beneficiaries in an easily available and accessible format, villagers in Cambodia could request their inclusion if they were particularly vulnerable. The same list was also used to ensure coordination with the government cash transfer scheme to avoid any corruption or mishandling (Dan Church Aid, 2021).

Collaboration with both public and private sectors have allowed for more sustained funding. In general as more NGO projects achieve tangible and visible success, there is an increased inclination to attract (financial) support of the public sector and established private sector. In this case the EFI has been operating predominantly in Chennai, but also in other Indian cities particularly in Tamil Nadu for a long period of time. The long history of community-based water body restoration in urban centres gives the NGO a certain sense of legitimacy as a reformer of water systems and thus private funders, community members and the PWD were more willing to work towards a common goal. This is also achieved through transparency and local knowledge and resource networks.

There is an increased adoption of open-source and free to use tools to generate and analyse data. This is particularly useful in the global South where public and private sector information systems and data availability is minimal and relatively weak or of lower resolution and quality. The Google Earth Engine is one such useful tool that is easy to learn and use in the global South that allows for a quality dataset to aid decision making (PAP02, 2022). Social entrepreneurs are also contributing to this data revolution by developing more specialised software for humanitarian and social sector applications such as Home Reto (PVT01, 2022).

Technology/Aspect	**Lake Restoration**	**Climate Campus**	**Functional Estimation Modelling**	**Volunteer Geographic Information**	**Cash Transfer System**
Key Successes	Complete ecological and hydrological restoration of traditional lake(s) to capture excess stormwater	Serious gaming to include and educate civil society in case of flooding	Forecast based financing of strategic preparedness measures in local villages with earmarked and disbursable funding	Real-time availability of bottom-up generated contextualised information of flood extent and impacts	Able to disburse cash at a rapid pace while remaining inclusive of vulnerable rural sections of society

Current Challenges	Large scale, network-wide replication of localised results and long-run cooperation with public and private sectors for funding and technical assistance	Scaling and consistently involving civil society, Reaching wider adoption and transferring knowledge	Long-run sources of funding and regional/international emulation of localised schemes	Automation of verification of information to reduce time required for data analysis, Replicability in other cities with different social media usage patterns, languages and internet access	Long-run funding of initiatives; 48 hour time requirement to set up cash distribution points; Occasional difficulty in accessing cash points during rainy season
Stakeholder Integration	State/Municipal Government, Residents, International NGOs, Established Private Firms (Media & Telecom)	Educational institutes, SMEs, Local Residents, Established Private firms in the gaming sector	International NGOs, National Government, Local Residents, Local Enterprises (Radios)	Municipal Governments, Local Residents, NGOs, Established Private Firms (Social Media)	National/Regional Governments, Village Administration, International NGOs, Local NGOs, Local Residents, Established Private Firm (Bank & Financial Service)
Emerging Solutions	Public sector schemes for network wide lake restoration encouraging involvement of NGOs and local residents as contributors; Educating local residents to assist with maintenance and preservation of progress	Accelerated risk perception and critical thinking regarding correct actions during a flood event	Increased level of international recognition could attract further funding and expansion; Continued cooperation from well funded international NGOs and aid agencies	Replication of system in cities within Indonesia; Increased availability of interfaces and open-source softwares to partially automate data management processes; Continued cooperation of social media firms	Increased test-bedding of anticipatory cash assistance to encourage use of cash for recovery, Use of mobile banking services available through apps or SMS

Discussions

<u>Best-practices should not be viewed in isolation:</u>

All the best-practices, while good examples, still have their limitations and drawbacks. However, there is a possibility to synergise their heterogeneity and parallelly use them. To elucidate, while the above review and case study identification aimed to identify current best-practices, each identified practice is not a panacea. This means that while they are best-practices at the point in time of the writing of this report, this may change very rapidly as the climate continues to change and so do the nature and magnitude of flood-risks in different parts of the world. However, that does not completely negate the utility of such a review. Instead, it serves as a starting point for the continued development of newer solutions to manage flood-risks. As addressed in the discussion sections of each case study, every best-practice had its pros and cons. However, in many cases the best-practice was one of many practices and measures taken as part of a greater whole. Thus, while best-practices are useful to investigate and emulate, they must not be applied in isolation. Instead, context plays an important role in providing insights to the existing system. Different structural and non-structural measures can interact with each other and manage flood-risks in different ways. Thus, a best-practice should never be viewed in isolation and nor should it be applied in isolation.

To exemplify the above, it is possible for the public and social sectors to collaborate with information management during the response phase during a flood event. The need for real-time and high resolution information exists to better inform response measures taken by the public and social sectors. The use of drones as seen in Fort Bend, provide high resolution data that can be used to analyse the extent of a flood and perhaps forecast its expansion over the next few hours. However, it does not provide socio-economic information. The data also takes a higher time and resource investment to process into a usable format. On the contrary, the PetaJakarta project was able to also provide real-time and high resolution information about the socio-economic impacts of the floods. The use of an open-sources platform provided greater accessibility to social actors who otherwise may not have been involved in assisting with the response measures and contributing to resilience. However, there is perhaps an opportunity to combine these solutions to create a common disaster response and risk management platform for both disaster management authorities and social sector actors to coordinate. This means that geographic, hydrological, geological, meteorological, social and economic data can be simultaneously collected, collated and processed. In this way, an even more nuanced view of the impacts of the flood can be observed which would allow both sectors to better tailor their responses to changing circumstances, thereby improving the flood resilience.

Examples of how such a multiple source integration can be meaningful and effective to increase resilience before, during and after a flood event can be found in the private sector. One such private firm that is working in this vein is the i-REACT project that was discussed previously. They combine the information from a large variety of stakeholders across the three major stakeholder groups. Firstly, they developed a smartphone application that was easily accessible to civil society members enabling the integration of VGI data which are then represented in an easy to comprehend visualisation. This ensures that the data generation process is democratised. The same application is also able to connect with control rooms of public sector first response agencies and integrated with geo-technical and hydrological data to provide a contextualised and real-time overview of the situation at hand. These are then related to first responders on the ground using smart-glasses technology which allows for fine-tuned response. While such platforms become increasingly adopted, continued development and improvements are required to ensure inclusivity of more stakeholders to aid in better resource mobilisation and high resolution data generation. The design of the application therefore needs to be inclusive of the everyday citizen and other stakeholders to ensure future versions are ergonomic for use during an emergency flood situation.

<u>Cyclical Nature of the DRM Cycle:</u>

Many feedback loops that were discussed connected backwards across stages in the DRM cycle. To explain in more detail, the DRM cycle was presented as a unidirectional process. This entails that at any given time, the progression of the cycle is fixed and it moves from one stage to another stage. However, the feedback loops demonstrate that this may not necessarily be the case. Some of the feedback loops created parallel positive effects across two or more stages simultaneously. Other loops worked 'backwards' against the usual flow of the cycle by contributing to flood-risk management in one of the preceding stages. Thus, this brings into question the cyclical nature of the DRM cycle and the flow of the process from one stage to another. It may be possible that the stages are more like states that can be used to categorise the stages of disaster-management like a framework rather than a fixed cycle.

To further exemplify and apply the above discussion for ease of understanding, the PetaJakarta case study comes handy. The main feedback loop identified was how the use of VGI mapping and open-source software mostly improved the response. However, the same platform that coordinated response measures was also used as a form of preparedness by at-risk populations which were yet to be inundated as they were able to monitor the progression of flooding in neighbouring areas. This provision of information thus also improved preparedness while the response phase was still active. This comes into conflict with the unidirectional and stage-by stage flow of the DRM cycle and becomes conceptually difficult to fit into the cycle as proposed by UCF (n.d.). It could be argued that different neighbourhoods in the case study were in different stages of the cycle, however, the complexity of social networks makes this difficult to analyse. Thus, it may be possible that a given flood may lead to the same region being in more than one state simultaneously. Thus, in this case study, it seems that the DRM cycle could be applied more like a framework for analysing and organising mechanisms than a clear chronological cycle.

In addition to the possibility of stages being states of flood-management rather than a cycle, it seems possible that a structural or non structural measure may be in two states simultaneously. To elucidate and exemplify, the use of modelling to prioritise the most effective nature-based solution for the local geographical and demographic context by the private firm Viridian Logic is a good case to demonstrate this phenomenon. Firstly, the implementation of prioritised nature-based solutions reduces the chance of flood occurrence, such as strategic forest plantation to reduce storm-water run-off into catchments can help prevent flooding by suppressing the rapid flow and accumulation of water. However, even if this nature-based solution proves insufficient to prevent flooding, the resultant flood would have substantially milder impacts as the flow of water is still slowed. This also makes the same solution a mitigative one. Therefore, the simultaneous preventative and mitigative capacity of nature-based solutions is clearly exhibited, further casting doubt on the fixed, unidirectional cyclical formulation of the DRM cycle.

<u>Communication technologies inherently connect Preparedness, Response, Recovery:</u>

In general, communication oriented technologies and to some extent forecasting systems often had simultaneous effects across these three stages. It was an interesting pattern given that the preparedness stage is a distinctly pre-disaster stage while response and recovery are considered as during and post-disaster phases. These compound effects are a particularly useful feedback loop due to its ability to integrate the various diverse stakeholders and sustain disaster-risk management strategies over a longer period of time.

The connection between preparedness and response could be seen in Nepal. The provision of the SMS early warning system acted as a kind of preparedness mechanism which informed villagers of an impending flood and ensured a larger proportion evacuated in time. This was especially crucial given the risk of flash floods means that the lead time was relatively short in most cases. However, the use of the Memorandum of Understanding with private companies, on the other hand, allowed affordable and free cell service to affected locals. This allowed vulnerable communities on ground to be able to communicate within each other and mobilise resources and assistance within themselves, improving flood response. The improved response and better preparedness indirectly facilitate recovery to a new normal as fewer resources are required for a community to achieve the pre-disaster level of resilience. In this particular scenario, there is no dedicated mechanism to ensure that communities are ‘built back better’ but the opportunity for them to do so can improve substantially. An almost identical set of feedback loops and mechanisms can be seen when analysing the use of Twitter and websites in the PetaJakarta initiative. These mechanisms are able to exist due to the use of communication to better collaborate between different stakeholders and in the case of the social sector within various organisations and individuals.

These capabilities are not just limited to the social sector. On the contrary, there is significant potential to leverage on private sector capabilities which remain mostly untapped. However, there are pioneer social entrepreneurs who are making a foray into this space in humanitarian focused participatory mapping. Home Reto is the pioneer embodying such an innovative technology and a socially oriented business model. They are currently developing an organisational tool tailored to suit the needs of the civil society sector. This allows the utilisation of humanitarian resources through efficient data usage to improve response and recovery by multi-stakeholder collaboration. This data emancipation equips civil society actors with the ability to more autonomously respond to flood-risks, hence improving credibility from the public sector point of view. Thus, this in turn bridges the communication and coordination gap between government officials, civil society and first responders. Over time, this can lead to a gradual shift to using a bottom-up approach to flood-risk management and thus flattening hierarchies. Hence, it is observable that there are simultaneous effects on raising resilience across preparedness, response and recovery through multi-stakeholder integration.

Synergy between Mitigation & Recovery

Another interesting synergy was observed between the mitigation and recovery stages. Usually, investing in one of the stages also improves flood-management and resilience in the other stage and vice versa.These stages require more investment and focus from stakeholders to transcend the prevention and response focussed paradigm. Investments and projects in these stages also tended to use a combination of structural and non-structural measures. Paying special attention to structural measures, nature-based solutions acting as a complement to existing grey structural infrastructure had this particular effect. The general argument behind these statements is that an investment in mitigation can reduce the damages caused by flooding to a given community and to its key infrastructure instalments. The reduced levels of damage thus frees up more resources to be dedicated to a post-disaster analysis of useful practices as well as possible areas of improvement. This knowledge can then be further acted upon to invest in strategies that can elevate resilience levels in vulnerabilities identified from the previous events.

Narrowing down the discussion to nature-based solutions and the public sector, the use of nature-based solutions in China as well as the United Kingdom reflect this synergy. In this case, nature-based solutions in China as part of its Sponge City Programme were designed to improve drainage and thereby reduce the physical and economic impacts of pluvial and fluvial floods. In doing so, nature-based solutions also tended to create other forms of value beyond flood defence. They aided in the provision of drinking water and cleaner air, thus improving the health of local communities. This form of multiple value creation placed local populations in a much better position to recover quickly and continue to invest in multi-functional solutions for future flood safety, becoming a potentially positive cycle. Similarly in London, the targeting of the most vulnerable social housing estates ensured that flood resilience was more equitably distributed across society and provided the capacity to mitigate future flooding and its associated impacts in those areas. The sustainability of these investments were further secured by involving local governments, NGOs as well as the residents themselves by empowering them to contribute and maintain the swales and other green infrastructure that were constructed.

A similar pattern was also observed in social sector led mitigating measures. The restoration of lakes within the ancient *eri* system in Chennai was a mitigation measure that could potentially aid recovery in the event of a future flood. The improvement of the water body allowed it to regain its hydrological functions, allowing it to store water and drain it down to an eri (tank/lake) further down the system. The mitigation measure is an adaptation to the increasing erraticity of rainfall in the region. By restoring its hydrological functions, the surrounding neighbourhood is able to better absorb the impacts of pluvial flooding that plagues the city and divert resources to restore more such water bodies as part of the system as well as continue to invest in the maintenance of the existing lake. Once again, the investment in mitigation seems to accelerate the pace of recovery. In this scenario, the restoration of the Madambakkam lake has now led to efforts to restore the Sithalapakkam Lake located further down the *eri* system, furthering the mitigation capacity of the region and enhancing its ability to recover from monsoonal pluvial flooding events.

2. Challenges, Expectations & Solutions

Over the course of the review and interviews, a variety of challenges, expectations and emerging solutions were identified. These were then sorted into themes for the purpose of discussion and summarised in a table.

Financial Resources & Institutional Support:

There is a lack of funding mechanisms for social initiatives that are sustainable and focussed on mitigation. Most aid agencies appeared to be focused on the provision of relief materials for flood response. While these initiatives are absolutely important to improve flood resilience, the effects do not last in the long-term. While the relief materials provide some protection and assistance in the short-run to enable flood affected persons to build back their livelihood, it does not necessarily fundamentally improve their resilience against floods for the next season. Such an increase in resilience is best achieved through investments in mitigative and recovery measures. The outlook for this is not bleak as aid agencies and the UN have begun testing out newer approaches. The UN was able to provide anticipatory cash assistance in Bangladesh to assist families in preparing for seasonal floods which proved highly effective compared to post-flood assistance. Similarly, public sector aid agencies have worked in assisting preparedness and recovery mechanisms in the global South. Funding from the German Foreign Ministry and Red Cross was able to fund the FUNES system implemented in southern Togo. This greatly improved the resilience of locals against fluvial flooding.

Moving beyond an economics-centric cost benefit analysis is also a major challenge associated with investing in mitigation, particularly nature-based solutions. It often defaults the scope of flood management that serves higher income areas with structural measures and investment. “Imagine you have a huge villa and Lamborghini, and during a flood you can get away with 400,000 euros of damage. If you live in a clay hut, the damage can be even more severe but amount to a 1000 euros. So, when using a cost-benefit analysis, the damage for the poorer people is by default lower than that of richer people. So you should avoid making a decision solely based on this cost-benefit analysis” (PAP02, 2022). However, newer methods of analysis are being made available. The bioswales in the social housing estates of London had a cost to benefit ratio of 1:4.39 based on calculating the various additional benefits provided by green infrastructure through the provision of ecosystem services as well as social and health benefits. A gradual positive change in this thought process of valuing flood-management interventions is thus observed.

Technology is thus framed as a force multiplier which can significantly improve resilience. However, developing and testing them is a difficult, demanding and occasionally serendipitous process which the public sector may not always be able to dedicate resources towards. Among the public sector there are often considerable expectations placed on the private sector to develop better technologies or find innovative solutions to complex problems (PUB01, 2022).

However, the Entrepreneurs interviewed explain a lack of initiative from the public sector to be supported in this endeavour. Not only this, but even when addressed directly through funding applications or the like, many Entrepreneurs with great ideas for innovative technologies are rejected. Reasons could include the contradictory expectation of having a minimum viable product to show. Since many of these products need to be developed in close collaboration with citizens or first responders, a minimum viable product would require more work than necessary. This is because certain technological features, and this holds especially true for communication technologies, might be unsuitable for e.g. civil society users and hence must be re-developed.

Furthermore, Entrepreneurs require business knowledge to scale up their solutions. This includes complex endeavours like market analysis of addressable clients, a sustainable business plan and accounting technicalities but also simply support in e.g. Human Resources or External Affairs Management. When reaching out to the public sector, there is often a slow or insufficient response leaving Entrepreneurs with disappointment in the public sector.

Finally, regulations and given practices on a government level are often outdated and in some cases even a major obstacle to design, test or implement new innovation in flood risk management. Pioneers in the flood risk management sector have already developed a wide range of solutions, be it of nature-based, engineering, techno-engineered, or socio-technological nature that can be employed for the decentralised management of flood risk.

Governance:

Rigid top-down approach and inflexible forms of governance are a norm in the public sector. This usually manifests as a disconnect between national water authorities and the municipal level governments. This often means that flood interventions at the national or river-basin level could often worsen the situation for certain municipalities by placing them at greater risk of floods. National authorities are also large in size meaning that a large proportion of resources are spent coordinating and managing decisions within the agency. They are also tied up with legislation which often slows down change by forcing them to commit resources to measures that may be outdated for current and future needs. The use of bottom-up measures that mandate local governments to play a bigger role can help alleviate the pressure placed on national authorities. By providing municipalities a higher level of executive and financial decision making power, the need for investing substantial resources in management and coordination is diminished. Furthermore, municipalities are in a better position to understand local contexts in an in-depth and detailed manner, which means that higher quality information can inform better decisions that suit local contexts. Ofcourse, municipalities must not be given absolute power as this could lead to competition between municipalities for lobbying for structural measures that may harm other municipalities (such as constructing dams which leads to large areas being permanently flooded). Instead, an intermediary river-basin level authority with some executive power may ensure a balance. This system is already followed to some extent in the Netherlands which is renowned internationally for its exemplary flood-management and acts as an international public sector-scale consultant.

A second key advantage of decentralising power to river-basin and local authorities is their ability to better rope in and network with other key stakeholders. At a smaller scale, it becomes administratively easier for the public sector to take into account the perspectives of diverse stakeholders, particularly civil society organisations and entrepreneurs. Decentralisation is a slow and tricky process but is definitely possible. One such example where decentralised executive powers may be beneficial is with the Water as Leverage scheme. The Greater Chennai Corporation was able to coordinate with the Water as Leverage team to design local water management and flood protection solutions which are socially relevant to Chennai's resident population and climate. The coordination with the municipality will allow for a prioritisation of key projects which would be simpler than if the scheme was taken up with the much larger state (Tamil Nadu) or national (India) governments.

Participation and Equity

Finally, a theme spanning over all stakeholders is crucial for multi-stakeholder engagement to acquire sustainable results. To achieve multi-stakeholder engagement, a certain sense of equity across and within stakeholders needs to be developed in an increasingly participatory oriented paradigm of flood-risk management. This could be achieved through dialogues where diverse actors get a say in designing and contributing towards flood-risk management measures and infrastructure. A participatory approach could improve prioritisation of effort and efficient resource mobilisation. Firstly, a participatory approach can bring together stakeholders who were previously ignored by technical-oriented institutions. These include civil society organisations, especially those involved in environmental issues and civic issues. These may also include entrepreneurs and smaller-scale firms involved more directly in flood-risk management. These more recently integrated stakeholders are able to provide various types of contextual information including socio-economic situations, local areas of vulnerability which may require prioritised intervention as well as local power dynamics. A snowball technique can also be used where these more directly involved stakeholders could bring in or consult with less directly involved stakeholders such as other local businesses, residential associations or locally influential individuals to create strong local knowledge and resource networks. These networks could be used to mobilise more resources for flood-risk management interventions as well as open up newer opportunities for collaboration, further intensifying and strengthening this network.

Creating the above network involves improving communication between stakeholders with different foci and capacities. Difficulties in crossing the technical versus non-technical barrier to inform vulnerable groups exist. However, these barriers have been transcended by projects and now more attention has been paid to this challenge, particularly in the global South. Social actors such as the Togolese Red Cross have been able to narrow this gap. Firstly, basic information is now being provided in a more accessible format. In the global South, the increased penetration of mobile services has allowed many at-risk individuals to be connected via SMS or calls. Similarly, even among the less literate sections of society, the use of radio services have ensured that information availability is inclusive. In particularly isolated regions, loudspeaker systems have also aided in spreading actionable information. Secondly, socio-economic information is increasingly integrated and compiled for ease of understanding for technically oriented public agencies by NGOs. Similar collaborations are visible in Chennai and in Cambodia within the discussed case studies. The democratisation of data generation through VGI mapping in Indonesia takes this up another notch by enabling individuals to contribute to the collaboration rather than being passive actors in the previous cases. The benefits of multi-stakeholder engagement through improved communication is increasingly being recognised and made use of.

Finally, the lack of inclusion of vulnerable populations in structural and non-structural measure design, implementation and maintenance was another identified issue. However, the adoption of participatory approaches is increasingly notable within local level public agencies throughout the world. The consultative and participatory approach that is partially driven by local residents and NGOs. For the case of social housing estates in London, the inclusion and enabling of social housing residents ensured that they were able to have a say in the process of constructing green infrastructure. This created a sense of inclusion and by extension involvement and investment in the green infrastructure and thus the community was able to contribute to its long-term maintenance. In doing so, the pressure on the local council to provide for the maintenance was reduced. Thus, the inclusion of vulnerable populations may also allow them to transform themselves from a passive stakeholder to an active actor who can also contribute to driving change towards improved resilience. This push of course is not just applicable to the public and social sectors but also from the private sectors. The case of softwares to ease bottom-up approaches to data generation is a particularly promising area.

The implementation of nature-based solutions is a particularly promising area where private sector involvement could more equitably distribute the socio-economically vulnerable. Viridian Logic's modelling system is able to take into account such socio-economic data and other local constraints into the model to determine the prioritisation of the best nature-based solutions. Concerning flexibility and inclusivity of the developed model, HydroloGIS, the start-ups scored very high. Besides being able to consider local constraints, it also takes into account the recreational aspects of the nature-based solution which encourages participation of locals and future opportunities of multiple value creation. Given that the outputs of these softwares are optimised for participatory design, consultation times and objections to development can be reduced by up to 2 years. This provides a more fair basis of decision-making, ensuring a more successfully implemented measure.

Scale & Scalability of Intervention:

Scale refers to the level of the intervention: the sub-local micro-level, the localised meso-level and the national/transnational macro-level. Scalability refers to whether the solution can be scaled from a lower level of implementation to a higher level to maximise resilience for a larger number of beneficiaries. The ability to scale-up solutions or intervene and reduce flood-risks for a large population by a substantial degree are desirable traits in any best-practice and are challenging to realise in practice. However, select practices have the potential to be scaled-up in a nuanced way without the high social and environmental costs associated with large-scale structural measures. Nature-based solutions tend to increasingly fill this niche. Nature-based solutions are typically focused on sub-local scales such as the neighbourhood level. This is often seen in the nature-based solutions implemented in the cases discussed. The swales in the Fulham and Hammersmith councils only served the three social housing estates they were constructed, one level below the micro-scale. On the micro-scale, the restoration of the Madambakkam lake had largely benefited residents of the surrounding area and indirectly others. While the Sponge City Programme is run at a macro-scale by the Chinese government, it is implemented at a micro-scale serving districts and neighbourhoods within Chinese megacities. Thus, nature-based solutions appear to not be very scalable. Conversely, networking nature-based solutions with existing grey infrastructure allows for increased scalability from micro to meso scales, thereby improving flood resilience and reach (PAP01, 2022).

This trend is already occurring in the private sector, particularly in Australia and the United States, where scalable technological solutions are being developed. Juliette Murphy, who experienced severe flooding in her lifetime, thus co-founded a multi-stage modelling system which can be scaled from a 1 metre grid resolution up to the national scale, in an effort to improve street-level data generation as well as integration of this data on a larger scale. This is exceptionally innovative and was previously deemed impossible to achieve (PVT04, 2022). This flexibility in scalability of the application allows it to be used in various capacities. Additionally the application allows the use of real-time data to conduct a rapid assessment of the situation, preventing the loss of lives and safeguarding key infrastructure installations.

Feedback Loops (Negative & Positive) (P)

Feedback loops were identified across all case-studies and all stages including in-depth discussion of results of all interviews conducted across various stakeholder groups. Most feedback loops identified were relatively positive in nature, whose mechanisms can be made better use of to more efficiently improve flood resilience. However, one negative feedback loop was noticed which could potentially trap a community or country in a vicious cycle. In general, an overly focused investment on preventative measures reduced flood-risks, but did not improve the resilience of the beneficiaries if it ever failed. Therefore, in the event of a failure, which is increasingly likely due to the adverse effects of climate change, the populations at risk remain heavily dependent on the public sector as they fail to develop independent resilience capacities. This higher risk and vulnerability makes them less able to contribute to flood responses in the event of the failure of a preventative measure that they become so dependent on. Thus, the public sector and the social sector are forced to spend substantial financial and non-financial resources on responding to floods. While this ensures most communities are able to bounce back to pre-flood levels of resilience, this fails to improve their status-quo. As flood-risks tend to rise with climate change, the stagnant level of resilience worsens the vulnerabilities in the long-run. This was observed in the recent floods in Germany where the population was less resilient due to the heavy dependence on preventative measures and public sector response mechanisms. The result was unprecedented levels of damage and fatalities (PUB03, 2022). The World Bank Group has estimated that between 1980 and 2009, the international community has spent 90 billion US$ on disaster-related assistance. Out of this total amount, prevention and preparedness accounted for only 3.6% at 3.25 billion, while emergency response and reconstruction accounted for the majority stake, US$86.34 billion. It is essential to move from the traditional response mechanism to a vision of prevention and resilience (Dan Church Aid, 2020). However, the adoption of risk-based flood-management across the globe has increased the prevalence of structural and nonstructural measures to adapt to changing climate. Many actors are gradually beginning to shift from this negative feedback loop between prevention and response to one driven by mitigation and recovery. Efforts by the public sector in this regard have culminated in programmes such as Sponge City Initiative in China as well as Sustainable Drainage Systems in the United Kingdom. Collaboration with social actors have also led to the formation of initiatives of this nature such as the Water as Leverage projects in Semarang (Indonesia), Chennai (India) and Khulna (Bangladesh) (PAP01, 2022). The gradual shift from a negative and vicious feedback loop to a positive and reinforcing feedback loop is occurring and will require continued study and investments in the long-term.

Summary of Key challenges and Emerging Solutions	
Challenges	**Emerging responses**
Financial Resources & Institutional Support	
Lack of sustainable humanitarian funding	Initiatives and earmarking of funds by aid agencies to invest in long-term mitigative civil society initiatives
Overuse of economic-centric cost-benefit analysis	Increased availability of alternative cost-benefit models for nature-based solutions
Lack of financial and business advice support for entrepreneurs	Improved funding from transnational and local governments; Start-up hubs
Governance	
Rigid, top-down governance structure slowing adaptation to changing climate	Decentralisation for ease of administration and facilitation of multi-stakeholder dialogues
Participation & Equity	
Weak participatory mechanisms	Use of communication technology to democratise data generation
Absence of voice for the most vulnerable sections	Specialised focus on most vulnerable sections, enabling them to take actions and contribute to resilience
Scale & Scalability of Intervention	
Scale of nature-based solutions are too small and locally focused	Ability to integrate with other infrastructure networks to boost scale and effects
Lack of flexibility in communication systems for local to global scale	Applications and systems are currently in development by entrepreneurs
Feedback Loops	
Vicious cycle of investment in prevention and response measures leads to high long-term costs	Gradual investments in mitigative measures to take advantage of mitigation and recovery positive feedback loop

[***Figure 1:*** *Summary Table of Challenges and Expectations*]

Limitations & Outlook

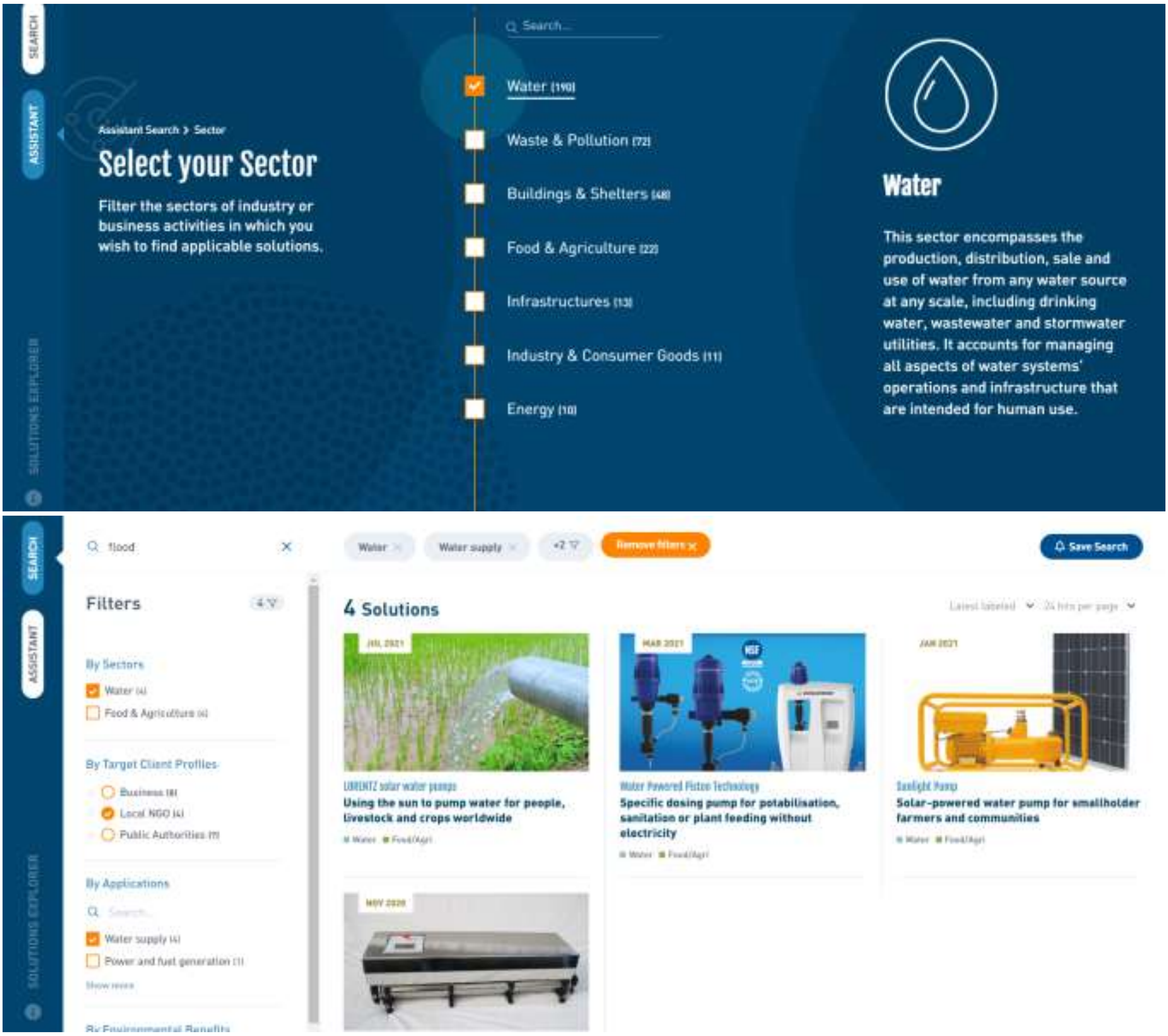
[***Figure 2:*** *Summary Infographic of Limitations and Outlooks*]

Disaster-management is a broad topic in which there are various kinds of disasters. Since the review focused on floods, future reviews should inquire into best-practices for other disasters. On the other spectrum of water-related disasters, droughts have also become increasingly common with climate change. The feedback loops noticed in flooding may also relate to droughts, particularly in cities such as Chennai where droughts and floods occur alternatively impacting overall water security and water-related disaster resilience. Another major climate related disaster that is on the rise is the increased severity and frequency of storms, especially with the El Niño and La Niña effects. Future research could also focus on these disasters. In addition to that, a single infrastructure may be useful for multiple hazards such as early-warning systems and nature-based solutions bringing about a multi-layer safety. This could also be further investigated (PAP01, 2022)

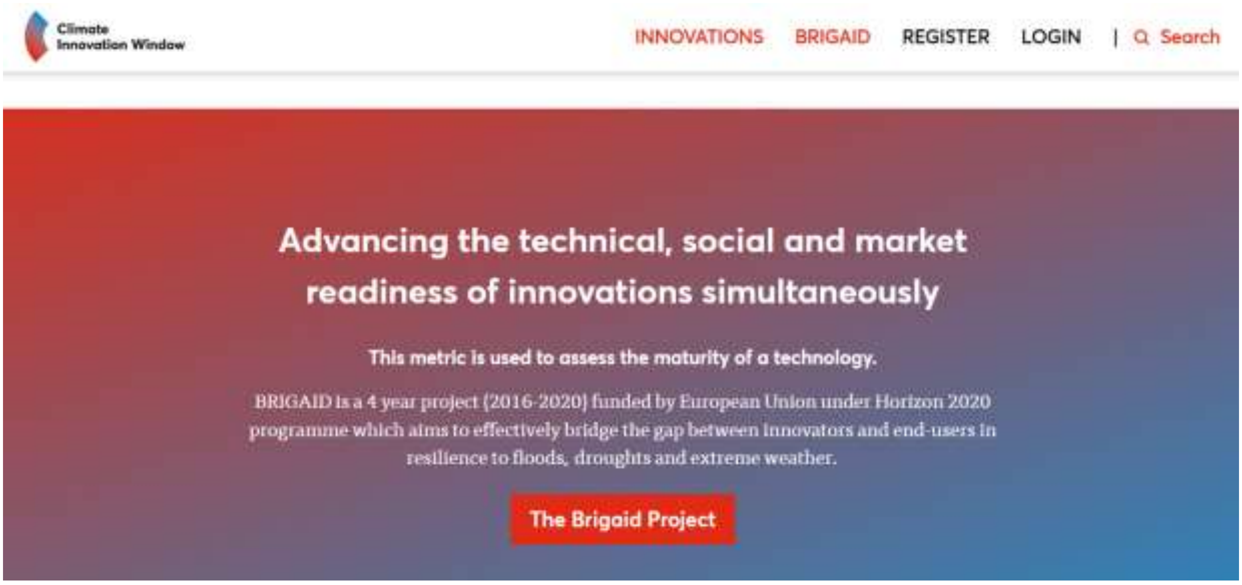
As discussed in the conceptual framework, the actual literature review methodology was simplified. This inherently leads to somewhat constrained comprehensiveness in identified case studies. Hence, the more comprehensive method developed by the researchers could ensure more certainty that the best practices found are truly the best among all existing ones. Furthermore, for the Entrepreneurship sector, a further limitation was the inability to access non-published start-up evaluations. Additionally, start-ups without any online presence, who could have had potentially interesting concepts, were inherently not included. Finally, also regarding the Start-up sector, very recently evaluated companies were less transparent in their challenges or generally less open to admitting barriers to scaling to not compromise on the competitiveness of profitability.

The conclusions derived from this review are relatively generic since it was often impossible to consider all context-specific adaptations needed if one wanted to replicate the given solution. Future studies could focus on one certain region to evaluate best-practices given individual context. These have already been implemented through various initiatives such as the Water as Leverage which is able to hyper-contextualise the impacts of multiple water-related hazards to a specific region. The frameworks developed in this report could be useful tools to create a holistic review with more implementable and tangible outputs for a local context.

Based on the above discussion, a flood-risk web-based platform is suggested as a useful trans-national tool to improve collaboration and construct new mechanisms for the flow of resources and knowledge on a global level to alleviate flood-risks in an era of climate change. A platform where different stakeholders could advertise their requirements (such as need for funding) or provide consultancy or collaborative options. The entrepreneurship sector in particular could use this as a platform to aid in the development and testing of their technologies. Public sector actors can more easily consult successful practices and interventions from other regions of the world facing similar risks and contexts. A global platform would simply aggregate and accelerate a series of processes (emerging solutions) that are already occurring independently.



[***Figure 3:*** *Possible Design for Transnational Web Platform (Solar Impulse, 2020)*]



[***Figure 4:*** *Possible Design for Transnational Web Platform (BRIGAID, 2020)*]

As seen in the above figures, there are already some global web platforms in existence. However, they do not have any communication functionality and do not yet have the capacity to involve the larger number of stakeholders who operate outside these platforms. Thus, a more comprehensive and collaborative-enabling global platform is required, perhaps implemented by the UNDRR to better facilitate potential exchanges and tighten the global knowledge and resource networks.

Concluding Remarks

The purpose of this report was to conduct a review of the status quo of best-practices in flood-risk management and point out current challenges and future outlooks. This involved developing a conceptual framework that was later applied to a complex literature search strategy to identify potential best-practices. This review succeeds in providing a general understanding and overview of the status quo while being as comprehensive as possible within the limited timeframe and resources with which it was conducted. The best-practice case studies are used to demonstrate the status quo from which general conclusions are drawn. Various key stakeholders were contacted for the purpose of conducting semi-structured interviews. The interviews were then thematically analysed to identify challenges faced by current stakeholders, expectations they hold of each other and highlight possible emerging solutions to these challenges. These data were then summarised in the format of a report for ease of reading. Among the various findings of the report, the most important one identified was that the biggest challenge in flood-risk management was the lack of a mechanism to encourage transnational and translocal collaborations to create a better network for the flow of resources and knowledge. Thus, the report concludes that developing such a (web-based) platform would be a concrete first step in improving flood-risk management globally.

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Appendix

Appendix A - Consent Form [EN]

DECLARATION OF CONSENT

for participation in the research study:

Executive Investigator(s)

Name(s): Natalie Perné, Pranav Shankar Kaundinya

Institution: University College Maastricht, Maastricht University

We are interested in understanding **best practices in technology for flood-risk management.** You will be presented with information relevant to our research study and asked to answer some questions about it. Please be assured that your responses will be kept completely confidential.

The study involves participating in an interview and should take you around 30 to 45 minutes to complete. The other option involves answering between 2 to 4 questions via email if an interview is not possible. Your participation in this research is voluntary. You have the right to withdraw at any point during the study, for any reason, and without any prejudice. If you would like to contact the executive researcher in the study to discuss this research, please e-mail.

We will make an audio recording of the interview and write down all that has been said during the interview on the basis of the recording. We will also make a written record of the email responses to our questions. In this written version of the interview and in our personal notes, we will not use your name. We shall instead address you with a pseudonym of choice. These documents will not be shared with anyone else. If we share any of the interview material with a third party, the interview will be anonymized so that you are not personally identifiable.

There are no reasonable foreseeable risks of participating in the study. Your participation will help to attain the stated purposes of the study. Your participation will not be compensated financially.

You have the right to access all the information collected about you as part of the study. Upon request, we will send you the information collected about you. After the study is completed, the outcome of our research will be presented in a written report. The information collected about you will have all been destroyed by 31/06/2022.

For research participants to sign:

• I have been informed of the study. I have read the written information. I have had the opportunity to ask questions about the study. I have been able to think about my participation in the study that is completely voluntary. I have the right to withdraw my consent and quit from the study at any time without needing to give a reason.

• I have agreed to participate in the study.

Name:

I am 18 years or older: ( )YES ( )NO

Date:

Signature:

Appendix B - Consent Form [TA]

சம்மதத்திற்கு அறிவிப்பு

ஆய்வில் பங்கேற்புக்கு:

நிர்வாக ஆய்வாளர்(கள்)

பெயர்(கள்): நாத்தாலி பெர்னே, ப்ரணவ் சங்கர் கௌண்டின்யா

நிறுவனம்: மாஸ்ட்ரிக்ட் பல்கலைக்கழக கல்லூரி, மாஸ்ட்ரிக்ட் பல்கலைக்கழகம்

வெள்ளப்பெருக்கு மேலாண்மையில் பயன்படுத்தும் தொழில்நுப சீர் செயல்பாடுகளைப் பற்றி மேலும் அறிய எங்களுக்கு ஆர்வம் உள்ளது. எங்களின் ஆய்வைப் பற்றி சில செய்திகளை பகிர்ந்த பிறகு, அவற்றைப் பற்றி சில கேள்விகள் கேட்கப்படும். உங்கள் பதில்கள் உங்கள் தனியுரிமையை கருத்தில்கொண்டு கையாளப்படும்.

இந்த ஆய்வில் ஓர் அங்கம் நேர்காணலில் பங்கேற்பது. இவை 30 நிமிடங்கள் முதல் 45 நிமிடங்கள் வரை எடுக்கலாம். ஒரு நேர்காணல் ஏற்பாடு செய்ய இயலாவிட்டால், மின்னஞ்சல் மூலமாக 2 முதல் 5 கேள்விகளுக்கு நீங்கள் பதிலளிக்கலாம். இவ்வாய்வில் பங்கேற்பது உங்கள் தன்னார்வம் சார்ந்திருக்கிறது. இவ்வாய்வின் போது எந்நேரமும் எக்காரணத்திற்காகவும் உங்கள் சம்மதத்தைப் பாரபட்சமில்லாமல் பின் வாங்கலாம். ஆராய்ச்சியைப் பற்றி பேச இவ்வாய்வின் நிர்வாக ஆய்வாளர் தொடர்பு கொள்ள விரும்பினால், மின்னஞ்சல் செய்தியை அனுப்பவும்.

நாங்கள் இந்த நேர்காணலை ஒலிப்பதிவு செய்வோம். ஒலிப்பதிவு அடிப்படையாகக்கொண்டு நேர்காணலில் பகிரப்பட்ட தகவல்கள் எழுதப்படும். மின்னஞ்சல் மூலமாக உங்கள் பதில்களை எழுத்து முறையில் குறிப்பிடப்படும். இந்த எழுத்து பதிப்பில் மற்றும் எங்களின் சொந்த குறிப்புகளில், உங்கள் பெயர் பயன்படுத்த மாட்டோம். அதற்குப் பதிலாக ஒரு புனைப்பெயர் பயன்படுத்தப்படும். இந்த ஆவணங்கள் வேறு யாரிடமும் பகிர படமாட்டா. மூன்றாம் தரப்பினருடன் நேர்காணல் குறிப்புகள் பகிர வேண்டிய சூழ்நிலை ஏற்பட்டால், உங்கள் அடையாளம் காணாதபடி முக்கிய தகவல்கள் மறைக்கப்படும்.

இவ்வாய்வில் பங்கேற்பதால் எதிர்பார்க்கக்கூடிய இடர்கள் ஒன்றுமில்லை. உங்கள் பங்கேற்பு எங்கள் குறித்த இலக்குகளை எட்ட உதவும். உங்கள் பங்கேற்புக்கு ஈடு தொகை வழங்கப்படாது.

இந்த ஆய்வில் உங்களைப் பற்றி நாங்கள் சேகரித்த தகவல்களை அணுக உங்களுக்கு உரிமை உண்டு. நீங்கள் கோரினால், அவை உங்களிடம் அனுப்பப்படும். ஆய்வு நிறைவு பெற்றதும், அதன் கண்டுபிடிப்புகள் ஓர் அறிக்கையாக வெளியிடப்படும். உங்களைப் பற்றி சேகரித்த தகவல்கள் அனைத்தும் 31/06/2022 தேதியில் மொத்தமாக அழிக்கப்படும்.

பங்கேற்பாளர் கையொப்பத்திற்கு:

- இவ்வாய்வு பற்றி தகவல் எனக்கு கிடைத்துள்ளது. அவற்றை நான் படித்துள்ளேன். ஆய்வைப் பற்றி கேள்விகள் எழுப்ப எனக்கு வாய்ப்பு கிடைத்தது. என் பங்கேற்பு பற்றி யோசித்த பிறகு, தன்னார்வத்துடன் இவ்வாய்வில் கலந்து கொள்வேன். என் சம்மதத்தை எந்நேரத்திலும், எக்காரணத்திற்காக பின்வாங்க எனக்கு உரிமை உள்ளது.

- இந்த ஆய்வில் பங்கேற்க சம்மதிக்கிறேன்.

பெயர்:

எனக்கு வயது 18-கு மேல் உள்ளது (தேர்வு செய்க): ( ) ஆம் ( ) இல்லை

கையொப்பம்:

Appendix C - WhatsApp Message for Snowball Strategy [EN/TA]

(English below | ஆங்கிலம் கீழே உள்ளது)

வணக்கம்!

நாங்கள் ப்ரணவ் மற்றும் நாத்தலி. நாங்கள் தொழில்நுட்பம், சமூக அமைப்புகள் மற்றும் வெள்ளப்பெருக்கைப் பற்றி ஆய்வு செய்கின்ற ஆராய்ச்சியாளர்கள். இந்த ஆய்வின் ஓரங்கமாக பல சமூக அமைப்புகளைப் நேர்காணல் / பேட்டி எடுக்கப்போகிறோம். 2015-இல் நிகழ்ந்த சென்னை வெள்ளத்தின்போது நடந்த மீட்புப்பணிகளை, வாட்ஸாப் போன்ற சமூக வலை தொடர்பு தொழில்நுட்பங்களால் எவ்வாறு நிர்வாகிக்கபட்டன என்பது எங்களது தலைப்பு. வெள்ளதின்போது மீட்புப்பணிகளில் ஈடுப்பட்டோருக்கு இச்செய்தியை முன்னனுப்பிவைக்கும்படி கோருகிறோம். பேட்டிகளை இணையம் (ஆன்லைன்) மூலம் நடத்தப்படும் அல்லது மின்னஞல் / வாட்ஸாப் மூலமாக ஒருசில கேள்விகளுக்கு பதிலளிக்கலாம். பேட்டிகள் தமிழிலோ ஆங்கிலத்திலோ நடத்தப்படும். உங்கள் தனியுரிமை / தகவல் பாதுகாப்பாக கையாளப்படும். இப்பேட்டியில் பெறபட்ட தகவல்கள், எங்களது இளநிலை ஆய்வறிக்கையில் சேர்க்கப்படும். உங்கள் பதிலுக்கு எங்கள் மனமார்ந்த் நன்றிகள்.

இப்படிக்கு,

ப்ரணவ் & நாத்தலி

வாட்ஸாப்: +65 9661 4124 | மின்னஞ்சல்: p.kaundinya@student.maastrichtuniversity.nl

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Greetings,

We are Pranav Kaundinya and Natalie Perné. We are researchers conducting research on technology, civil society and flooding. As a part of this research, we are conducting interviews of NGOs and civil society organisations. We are particularly interested in the use of communication technology such as WhatsApp as a tool to coordinate response efforts during the Chennai Floods of 2015. We would highly appreciate it if you could forward this message to people who were involved in the flood response and recovery efforts. If possible, we hope to conduct an interview online. If not, we would appreciate it if you could answer one or two written questions. We can conduct the interview in Tamil or English. Your response will be treated with utmost privacy. Your insights would be anonymously included in our undergraduate research report. We thank you for your response.

Regards,

Pranav & Natalie

WhatsApp: +65 9661 4124 | Email: p.kaundinya@student.maastrichtuniversity.nl

Appendix D - Sample Interview Guide for Public Sector

Relevant Documents:

Research Paper(s):

Khosravi, K., Shahabi, H., Pham, B. T., Adamowski, J., Shirzadi, A., Pradhan, B., Dou, J., Ly, H. B., Gróf, G., Ho, H. L., Hong, H., Chapi, K., & Prakash, I. (2019). A comparative assessment of flood susceptibility modeling using Multi-Criteria Decision-Making Analysis and Machine Learning Methods. *Journal of Hydrology*, *573*, 311–323. https://doi.org/10.1016/j.jhydrol.2019.03.073 https://www.sciencedirect.com/science/article/pii/S0048969720315795

Key Points:

- Using models to predict flooding can help guide actions towards mitigating flood damage or focus on prevention of such flooding events in a given area
- Machine Learning models proved to be more effective than Multi-Criteria Decision Making models as they use a pre and post-pruning process to avoid 'overfitting' the model to the data
- Full dykes are higher than semi-dykes and prevent allflooding while semi-dykes do not prevent monsoonal flooding
- The flood reduction ability of a dyke depends on whether it is full or semi and also depending on the type of dyke

Questions:

- What are some of the major challenges facing the public sector in flood-risk management currently? Where or why do they arise?
- Does the public sector place any major barriers to the adoption of GIS technology and machine learning for flood-risk assessment? How could these barriers be removed?
- Of the stages of the disaster-risk management cycle (prevention, mitigation, preparedness, response and recovery), where do you feel the public sector could make the maximum impact?
- With regards to machine learning and GIS technology, is a public sector push sufficient or do the private and social sectors also need to get involved to maximise its effectiveness in flood-risk management?

Appendix E - Sample Interview Guide for Private Sector

Generic questions:

1) How do you reflect about your best-practice case study: What were your challenges and how did you overcome them?
2) How does your technology score among Innovation, Profitability for growth and Human impact (Multi-value creation)? Do you have additional data we could use to better quantify those factors?
3) What barriers do you face in the future? Which expectations do you have from other stakeholders like the government or citizens to overcome barriers?

Generic questions - extended:

1) How do you reflect about your best-practice case study: What were your challenges and how did you overcome them?
How did the partnership with <Company/Partner> accelerate the project?
Adaptation and sustainable transformation

1. How did the partnership between <Companies/Partners> accelerate the technologies developed and their impact? What were key challenges and how were they overcome?

2) How does your technology score among Innovation, Profitability for growth and Human impact (Multi-value creation)?
Do you have additional data we could use to better quantify those factors?

2. How would you rate <Company> on Innovation, Profitability and Human impact (Multi-value creation, increasing resilience) ?

3) What barriers are you facing (i.e. financial, technical, adoption by stakeholders) ?
Which expectations do you have from other stakeholders like the public (e.g. government, UN) or social sector (e.g. citizen´s, NGO´s) to overcome barriers?

3. What barriers are you facing and which expectations do you have from other stakeholders ?

Appendix F - Sample Interview Guide for Social Sector [EN/TA]

எழுத்து மூலம் நேர்காணல் தாள்

பெயர்: ____________________________ **தேதி**: ________________

1) உங்கள் அனுபவத்தில், வெள்ளத்தின்போது வாட்ஸாப்/ ஃபேஸ்புக்/தொலைபேசி போன்ற சமூகவலைதளங்களை நீங்கள் எவ்வாறு பயன்படுத்தினீர்கள்?

2) சமூகவலைதளங்களின் பயன்பாட்டினால் எல்லா பங்குதாரர்கள் பலனடைந்தார்களா? யார் அதிகமாக பலனடைந்தார்கள்? யார் இவற்றிலிருந்து தவிர்க்கப்பட்டார்கள்?

3) மீட்புப்பணிகளில் நீங்கள் ஈடுபடும்போது, எந்த சமூக அமைப்புகளுடன் இணைந்தீர்கள்?

4) மீட்புப்பணிகளை மேலாண்மை செய்வதில் சமூகவலைதளங்கள் வேறு விதமாக பயன்படுத்திருக்கலாம் என்று உணர்கிறீர்களா? ஏன்?

5) வெள்ளத்தினால் ஏற்படும் பதிப்புகளைக் கையாள, சமூக வலைதளங்கள் ஒரு முக்கிய கருவி என்று நினைக்கிறீர்களா? இல்லை என்றால், எக்காரணத்தால் நீங்கள் அப்படி யோசிக்கிறீர்கள்? வெள்ளத்திற்கு ஒரு தனிப்பட்ட செயலியை (ஆப்ஸ்) அரசு தயாரித்து வெளியிட வேண்டும் அல்லது குறுன்செய்தி தகவல் (SMS) சேவை தொடக்க வேண்டும் என்று நினைக்கிறீர்களா? உங்கள் எதிர்பார்ப்புகள் என்னென்ன?

<u>பங்குதாரர்</u> - வெள்ளத்தால் பாதிக்கபட்டோர், மீட்புப்பணியாளர், அரசு அலுவர், சமூகப்பணிதில் ஈடுபடுவோர் போன்றவர்கள்

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Written Interview Sheet

Name: ______________________________ Date: _________________

1. In your personal experience, how were you able to make use of WhatsApp, Facebook and other social media platforms during the floods?
2. Do you feel that all stakeholders were able to benefit from social media use? Who do you feel benefited the most? Who do you think were excluded?
3. Were there any civil society organisations you had worked with for relief efforts?
4. Do you feel that social media could have been used in a different way to manage the relief efforts for the floods?
5. In the future, do you see social media as a useful tool for flood-risk management? If not, why? Do you feel that the government should create a specialised app for the public to download or create an SMS service? What are your expectations?

Stakeholders - Flood victims, First Responders, Government Officials, Civil Society Volunteers/Members

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Appendix G - Summary of unknown source of all publications i-REACT (Case-study Entrepreneurship Stage Response)

#	Type	Title	Authors	Publication Year	DOI	Downloac	Type	Journal	Funder	Project N	Access
	dataset	Emergency management/Natural Hazards: annotated tweets	Rossi, Claudio;Acerbo, Flavia Sofia;Ylinen, Kaisa;Juga, Ilkka;Nurmi,	01/02/2019	10.5281/z	https://dc	Dataset		European	I-REACT(7	Open Access
	publication	The design of a mobile application for crowdsourcing in disaster risk reduction	Nguyen, Q. N.;Antonella Frisiello;Rossi, C.	19/05/2019	10.5281/z	https://dc	Conferen	Scopus - E	European	I-REACT(7	Open Access
	publication	Quantifying and minimizing the impact of disasters on wireless communications	Francesco Malandrino;Carla-Fabiana Chiasserini	12/12/2017	10.5281/z	http://hdl	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	Scheduling of emergency tasks for multiservice UAVs in post-disaster scenarios	Cristina Rottondi;Francesco Malandrino;Andrea Bianco;Carla-Fabia	23/10/2020	10.1016/j.	https://dc	Article	Crossref	European	I-REACT(7	Open Access
	publication	Early detection and information extraction for weather-induced floods using social media streams	Claudio Rossi;Flavia Sofia Acerbo;Kaisa Ylinen;Ilkka Juga;Pertti Nur	06/03/2018	10.5281/z	https://dc	Article	Crossref	European	I-REACT(7	Open Access
	publication	Deep learning models for passability detection of flooded roads	Lopez-Fuentes, L.;Alessandro Farasin;Skinnemoen, H.;Garza, P.	29/10/2018	10.5281/z	http://ww	Conferen	Scopus - E	European	I-REACT(7	Open Access
	publication	A language-agnostic approach to exact informative tweets during emergency situations	Jacopo Longhini;Claudio Rossi;Claudio Casetti;Federico Angaramo	11/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	Calibrating Ensemble Forecasts to Produce More Reliable Probabilistic Extreme Weather Forecasts	Ylinen, Kaisa;Kilpinen, Juha	20/05/2018	10.5281/z	https://dc	Conference object		European	I-REACT(7	Open Access
	publication	Area Formation and Content Assignment for LTE Broadcasting	Claudio Casetti;Carla-Fabiana Chiasserini;Francesco Malandrino;Ca	19/07/2017	10.5281/z	https://dc	Article	Crossref	European	I-REACT(7	Open Access
	publication	Area Formation and Content Assignment for LTE Broadcasting	Claudio Casetti;Carla-Fabiana Chiasserini;Francesco Malandrino;Ca	19/07/2017	10.5281/z	https://dc	Article	Crossref	European	5G-Crossh	Open Access
	publication	Cloud Architecture for Mobile Geolocated Emergency Services	Rossi, C.;Heyi, M. H.;Scullino, F.	16/11/2016	10.5281/z	https://dc	Article	Concurrer	European	I-REACT(7	Open Access
	publication	Cloud Architecture for Mobile Geolocated Emergency Services	Rossi, C.;Heyi, M. H.;Scullino, F.	16/11/2016	10.5281/z	https://dc	Article	Concurrer	European	FLOODIS(I	Open Access
	publication	Multi-modal deep learning approach for flood detection	Lopez-Fuentes, L.;Joost van de Weijer;Bolanos, M.;Skinnemoen, H.	23/10/2017	10.5281/z	https://dc	Conferen	Scopus - E	European	I-REACT(7	Open Access
	publication	Gamified Crowdsourcing For Disaster Risk Management	Frisiello, Antonella;Nhu Nguyen, Quynh;Rossi, Claudio;Dominici, F	11/12/2017	10.5281/z	https://dc	Conference object		European	I-REACT(7	Open Access
	publication	A heat wave forecast system for Europe	Andrea Gobbi;Azra Alikadic;Kaisa Ylinen;Federico Angaramo;Cesar	11/12/2017	10.1109/b	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	All in a twitter: Self-tuning strategies for a deeper understanding of a crisis tweet collection	Evelina Di Corso;Francesco Ventura;Tania Cerquitelli	11/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	Review on computer vision techniques in emergency situations	Laura Lopez-Fuentes;Joost van de Weijer;Manuel GonzÃ¡lez-Hidalg	16/10/2017	10.1007/s	https://dc	Article	Crossref	European	I-REACT(7	Open Access
	publication	a machine learning approach	Flavia Sofia Acerbo;Claudio Rossi	12/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	Online clustering and classification for real-time event detection in Twitter	Angaramo, F.;Claudio Rossi	20/05/2018	10.5281/z	https://dc	Conferen	Scopus - E	European	I-REACT(7	Open Access
	publication	Summarization of emergency news articles driven by relevance feedback	Luca Cagliero	11/12/2017	10.1109/b	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	Analyzing spatial data from twitter during a disaster	Luca Venturini;Evelina Di Corso	11/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	dataset	Synthetic geospatial data for performance analysis of geospatial database systems	Garza, Paolo	08/11/2017	10.5281/z	https://dc	Dataset		European	I-REACT(7	Open Access
	publication	Planning UAV activities for efficient user coverage in disaster areas	Francesco Malandrino;Carla-Fabiana Chiasserini;Claudio Casetti;Lu	29/11/2018	10.1016/j.	http://hdl	Article	Crossref	European	I-REACT(7	Open Access
	publication	Methods to Remove the Border Noise From Sentinel-1 Synthetic Aperture Radar Data: Implications	Ali, Iftikhar;Cao, Senmao;Naeimi, Vahid;Paulik, Christoph;Wagner,	17/01/2018	10.5281/z	https://dc	Article	Crossref	European	I-REACT(7	Open Access
	publication	Gamified crowdsourcing for disaster risk management	Antonella Frisiello;Quynh Nhu Nguyen;Claudio Rossi	15/01/2018	10.1109/b	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	Automated Delineation Of Wildfire Areas Using Sentinel - 2 Satellite Imagery	Weirather, Mira;Zeug, Gunter;Schneider, Thomas	03/07/2018	10.5281/z	https://dc	Article		European	I-REACT(7	Open Access
	publication	Co-design of a crowdsourcing solution for disaster risk reduction	Quynh Nhu Nguyen;Antonella Frisiello;Claudio Rossi	12/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	Localization of Emergency First Responders Using UWB/GNSS with Cloud -based Augmentation	Tadic, S.;Vurdelja, L.;Vukajlovic, M.	12/12/2017	10.5281/z	https://dc	Conference object		European	I-REACT(7	Open Access
	publication	Multiservice UAVs for Emergency Tasks in Post-disaster Scenarios	Francesco Malandrino;Cristina Rottondi;Carla-Fabiana Chiasserini;/	14/05/2019	10.1145/3	http://hdl	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	PERCEIVE: Precipitation Data Characterization by means on Frequent Spatio-Temporal Sequences	Alessandro Farasin;Garza, P.	20/05/2018	10.5281/z	https://dc	Conferen	Scopus - E	European	I-REACT(7	Open Access
	publication	Positioning integrity computation for consumer grade GNSS receivers	Gianluca Marucco;Davide Margaria	12/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	SQL versus NoSQL databases for geospatial applications	Elena Baralis;Andrea Dalla Valle;Paolo Garza;Claudio Rossi;Frances	11/12/2017	10.5281/z	http://hdl	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	Optimal Throughput Management in UAV-based Networks during Disasters	Luca, Chiaraviglio;Lavinia, Amorosi;Francesco, Malandrino;Chiasser	24/09/2019	10.1109/ir	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
	publication	short paper	Srdjan Tadic;L. Vurdelja;Milan B. Vukajlovic;Claudio Rossi	11/12/2017	10.1145/3	https://ze	Conferen	Crossref	European	I-REACT(7	Open Access
35	publication	short paper	Srdjan Tadic;L. Vurdelja;Milan B. Vukajlovic;Claudio Rossi	11/12/2017	10.1145/3	https://ze	Conferen	Crossref	European	I-REACT(7	Open Access
36	publication	River segmentation for flood monitoring	Laura Lopez-Fuentes;Claudio Rossi;Harald Skinnemoen	11/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
37	publication	Scaling associative classification for very large datasets	Luca Venturini;Elena Baralis;Paolo Garza	08/12/2017	10.1186/s	http://arx	Preprint	Journal of	European	I-REACT(7	Open Access
38	publication	Coupling early warning services, crowdsourcing, and modelling for improved decision support and	Conrad Bielski;P. Gamez;MarichÃ© NavÃ-o Navarro;Azra Alikadic;[	11/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
39	publication	The role of unstructured data in real-time disaster-related social media monitoring	Francesco Tarasconi;Michela Farina;Antonio Mazzei;Alessio Bosca	11/12/2017	10.5281/z	https://dc	Conferen	Crossref	European	I-REACT(7	Open Access
40	publication	Report on Data Visualization Design				https://w	Project deliverable		European	I-REACT(7	Open Access
41	publication	Report on Cost-Benefit Analysis				https://ec	Project deliverable		European	I-REACT(7	Open Access
42	publication	Report on Communication, Dissemination and User Engagement - Issue 1				https://w	Project deliverable		European	I-REACT(7	Open Access
43	publication	Report on Technical Requirements and Overall System Architecture				https://w	Project deliverable		European	I-REACT(7	Open Access
44	publication	Final Report				https://ec	Project deliverable		European	I-REACT(7	Open Access
45	publication	I-REACT System documentation and training pack				https://ec	Project deliverable		European	I-REACT(7	Open Access
46	publication	Initial Plan on Dissemination, Communication and User Engagement				https://w	Project deliverable		European	I-REACT(7	Open Access
47	publication	Report on Users and Stakeholders requirements analysis, operational procedures, processes and scenarios				https://w	Project deliverable		European	I-REACT(7	Open Access
48	publication	Data Management Plan				https://w	Data Management P		European	I-REACT(7	Open Access
49	publication	Final International Conference				https://ec	Project deliverable		European	I-REACT(7	Open Access
50	publication	Open Data and historical products module				https://w	Project deliverable		European	I-REACT(7	Open Access
51	publication	Report on EGNSS integration				https://w	Project deliverable		European	I-REACT(7	Open Access
52	publication	Report on the system demonstration				https://ec	Project deliverable		European	I-REACT(7	Open Access
53	publication	Report on Gamification and engagement				https://w	Project deliverable		European	I-REACT(7	Open Access
54	publication	Project video and final presentation				https://ec	Project deliverable		European	I-REACT(7	Open Access
55	publication	Communication pack				https://w	Project deliverable		European	I-REACT(7	Open Access
56	publication	Report on Emergency Management Systems, European Early Warning Systems and Sentinel data integration				https://w	Project deliverable		European	I-REACT(7	Open Access
57	publication	Report on Communication, Dissemination and User Engagement - Issue 2				https://ec	Project deliverable		European	I-REACT(7	Open Access
58	publication	Report on Open Data and Historical Events Data integration				https://w	Project deliverable		European	I-REACT(7	Open Access
59	publication	Report on Communication, Dissemination and User Engagement - Issue 3				https://ec	Project deliverable		European	I-REACT(7	Open Access
60	publication	Report on Multi Hazard requirements analysis				https://w	Project deliverable		European	I-REACT(7	Open Access
61	publication	Report on Models and Engines				https://ec	Project deliverable		European	I-REACT(7	Open Access
62	publication	Report on design of the Big Data Architecture, Linked Data & Semantic Structure				https://w	Project deliverable		European	I-REACT(7	Open Access
63	publication	Filtering informative tweets during emergencies	Acerbo, Flavia Sofia;Rossi, Claudio			https://dc	Conferen	isbn: 978	European	I-REACT(7	not available
64	publication	Localization of emergency first responders using UWB/GNSS with cloud-based augmentation	Tadic, S.;Vurdelja, L.;Vukajlovic, M.;Rossi, Claudio			https://dc	Conferen	isbn: 978	European	I-REACT(7	not available

Please consult the authors for the Excel file

Appendix H - Sample Email Invite for Interview with Potential Interviewee [DE]

[DE]

Sehr geehrter Herr [redacted]

Im Laufe der letzten Wochen haben wir eine Bewunderung für Ihre Forschung und Arbeit entwickelt. Wir hoffen, Ihre professionelle und akademische Meinung zu Technologien und deren Potenzial zur Miteinbeziehung der Zivilgesellschaft und der privaten Wirtschaft in den Bereich des Katastrophen Risikomanagements, zu konsultieren. Unsere Forschung bezieht sich nicht nur auf Best-Practice Fallstudien, sondern setzt sich auch mit den Herausforderungen von Multi-Stakeholder-Inklusivität auseinander. Schließlich führen wir einerseits Interviews mit Unternehmern, um herauszufinden, wie R&D in der Privatwirtschaft das Tempo und die Effektivität von Innovationen für alle Beteiligten beschleunigen kann. Andererseits führen wir auch Interviews mit Mitgliedern zivilgesellschaftlicher Organisationen, die Hilfsmaßnahmen während der Überschwemmungen im Jahr 2015 in Chennai, Indien, koordiniert haben, mit besonderem Fokus auf Kommunikationstechnologie.

Wir würden uns sehr freuen, wenn Sie Zeit für ein kurzes 20 bis 30 minütiges, virtuelles Interview Zeit hätten. Gerne in Deutsch oder Englisch, wir richten uns nach ihrer Präferenz. Wir sind auch offen das Interview in Deutschland durchzuführen, wenn es sich bei dem Anreiseweg von Maastricht um wenige Student handelt. Sollte ein Interview nicht möglich sein, wären wir Ihnen dennoch sehr dankbar, wenn Sie einige Fragen per E-Mail beantworten könnten.

Das Ergebnis unserer Forschung, welches hoffentlich auch Ihre Erkenntnisse beinhalten wird, wird auf der Maastricht Research Based Learning Konferenz präsentiert. Unser Vorgesetzter, [redacted] der bei UNU Merit angestellt ist, gab uns auch die Gelegenheit, auf dem (in unserem E-Mail-Gespräch erwähnten) Flood Knowledge Summit zu präsentieren.

Ein Bericht, der unsere Best-Practice Fallstudien und qualitative Multi-Stakeholder-Forschung zusammenfasst, wird für Stakeholder verfügbar sein.

Mit freundlichen Grüßen,

[redacted]