Hertie School of Governance

June 2020

GROUNDING SPACE

Potentials and Pitfalls of Remote Sensing for Risk-Informed Development in Fragile Contexts

Master Thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts (M.A.)

Supervisor: Prof. Dr. Luciana Cingolani

Hertie School of Governance
Friedrichstraße 180
10117 Berlin, Germany

Student: Tim Hildebrandt
Email: t.hildebrandt@mia.hertie-school.org

Study Program: Master of International Affairs (MIA)

Word Count: 13 174

ABSTRACT

Special times require special measures. Where fragility, conflict and violence prevail, it is the moment of satellite remote sensing (RS). This thesis examines the question to what extent RS improves disaster risk analyses in fragile contexts. Under the lens of evidence-based policymaking, this work triangulates the state of the art in the literature with eleven expert interviews. Both the process and the outcome of RS activations are conditional and require several support factors to unleash its full potential. These conditions mainly apply to non-fragile contexts, whereas fragile contexts are characterized by the absence and deterioration of these conditions and support factors as well as different sets of negative and inhibiting factors. Under certain circumstances, RS does not improve disaster risk analyses and has ambiguous feedback effects in fragile contexts. In some cases, the disaster risk analysis with RS has proven to be a risky endeavor in itself, neither politically sensitive nor conflict-neutral. Policy recommendations encourage intra- and inter-organizational learning and action, open debates, project evaluation, resource pooling and cooperation to pave a safer way toward risk-informed development.

Table of Content

ABBREVIATIONS

BBK	German Federal Office for Civil Protection and Disaster Assistance
BMZ	German Federal Ministry for Economic Cooperation and Development
CEMS	Copernicus Emergency Management Service
DG ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations (European Commission)
DLR	German Aerospace Agency
DNH	Do-No-Harm
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EaR	Elements at Risk
e.g.	exempli gratia (latin expression for ‘for example’)
EO	Earth Observation
EO4SD	Earth Observation for Sustainable Development
ESA	European Space Agency
FAO	Food and Agriculture Organization
FCV	Fragility, Conflict, Violence
GIS	Geospatial Information System
GIZ	German Corporation for International Cooperation GmbH
GRAF	Global Risk Assessment Framework
INUS condition	Insufficient, but Necessary part of an Unnecessary but Sufficient condition
IO	International Organization
IOM	International Organization for Migration
Maxar	Maxar Technologies (Space Technology Company)
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization
ODI	Overseas Development Institute
OECD	Organisation for Economic Co-operation and Development
RS	Remote Sensing (in this work: Satellite Remote Sensing)
UN	United Nations
UNEP	United Nations Environment Program
UNDP	United Nations Development Program
UNDRR	United Nations Office for Disaster Risk Reduction
UNHCR	United Nations High Commissioner for Refugees
UNI	Unintended Negative Impacts
UNITAR	United Nations Institute for Training and Research
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNOOSA	United Nations Office for Outer Space Affairs
UNOSAT	UNITAR's Operational Satellite Applications Programme
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
USD	United States Dollar
w/o	without

"Earth observation data can greatly assist countries in assessing current risk trends with a view to determining the most pressing priorities that their disaster risk reduction strategies need to address."

- Mami Mizutori (2018)[1], Special Representative of the UN Secretary-General for Disaster Risk Reduction & Head of the UN Office for Disaster Risk Reduction (UNDRR)

I. INTRODUCTION

All over the world, humans, assets and ecosystems are exposed to risks from natural disasters. Extreme weather events such as floods and storms as well as slow-onset events such as droughts and soil erosion occur with increasing intensity and frequency. The economic and human costs of disasters are enormous. In 2017, the total economic damage inflicted by disasters worldwide reached 345 billion USD — the second-biggest figure to date (MunichRE 2018). Every year, extreme weather events cause around 70,000 deaths and drive 26 million people into poverty. The scale of loss and damage is exacerbated by climate change, population growth, environmental destruction and the expansion of human activities into high-risk areas (CRED/UNDRR 2018). Generally, several digital tools are at the forefront to combat disasters, from mobile applications to climate modelling. One of the key tools to support disaster risk analyses is satellite remote sensing (RS). In academic debates however, RS is seldom linked to disasters in contexts affected by fragility, conflict and violence (FCV, in the following short: 'fragile'). Therefore, this thesis contributes to close the gap of systematic assessments on the significance of digital tools for understanding risks.

Moreover, particularly fragile states lack the capacity to protect their population from disasters. As a result, people and infrastructure become more vulnerable and exposed to extreme weather events (ODI 2019). Among developing countries, fragile states are likely to suffer the worst effects of climate change and loss of biodiversity. The combination of aggravating factors increases disaster risks and potentially undermines previous development gains (BMZ, 2019). Finally, the COVID-19 pandemic is expected to exacerbate negative trends such as 'backsliding democracies' and 'creeping autocratization' worldwide, which contribute to fragility (Bertelsmann Stiftung 2020).

[1] United Nations Office for Disaster Risk Reduction (2019): on the occasion of the GEO-XV Plenary which was part of GEO Week 2018 see URL: https://www.undrr.org/news/earth-observation-data-essential-drr.

The terminology of this work focusses on Disaster Risk Reduction (DRR), which aims at preventing new and reducing existing disaster risk to strengthen resilience and sustainable development. In turn, Disaster Risk Management (DRM) is the application of DRR policies (UNDRR 2020a-b). Identifying and understanding risk is the foundation of DRR and essential for all subsequent policy actions. Therefore, the disaster risk analysis is the key element for DRM. In light of the current challenges, however, DRM-policymakers face a dual challenge: disaster risk analyses are more difficult *and* more necessary to conduct in fragile contexts compared to non-fragile contexts — for example due to ongoing conflicts. Moreover, disasters predominantly affect people and assets in fragile contexts: according to the Overseas Development Institute (ODI) flagship report *When Disasters and Conflict Collide* (2019), 58 percent of deaths from natural hazard-related disasters occur in the world's 30 most fragile states. Finally, the latest OECD *States of Fragility* report (2019) concludes that 80 percent of the world's poorest people could be living in fragile contexts by 2030.

RS is increasingly used at all stages of DRM from preparedness to response and at local to global levels of governance. More than 40 nations are identified as having invested in RS, amounting to investments of 7-8 billion USD per year (ESA 2015: 6). Furthermore, the global RS market generated over 7 billion USD in 2018 and is estimated to grow over nine percent between 2018 and 2023 (Reportlinker 2019). In light of these interdisciplinary developments, this work asks a cutting-edge research question: *Does remote sensing improve disaster risk analyses in fragile contexts?*

The following *Chapter II* introduces the perspective of evidence-based policymaking. The literature review in *Chapter III* describes the current disaster risk governance architecture and *Chapter IV* explains the origin of the problem to conduct disaster risk analyses in fragile contexts. Subsequently, *Chapter V* exhibits details of RS. The desk study in *Chapter VI* reveals publications on RS activations. The focus is on the empirical analysis in *Chapter VII*, which triangulates the previous literature by examining eleven expert interviews from national aerospace agencies and administrations, humanitarian-, development- and UN organizations and the private sector. *Chapter VIII* summarizes key findings and *Chapter IX* entails the discussion. Lastly, this work presents policy recommendations for different key stakeholders in *Chapter X* and draws the conclusion in *Chapter XI*. This work examines the potentials and pitfalls of RS from different academic and professional perspectives. Thus, the title 'Grounding Space' is meant as a critical reflection of and a contribution to different communities of practice to enable risk-informed decision-making.

II. EVIDENCE-BASED POLICYMAKING

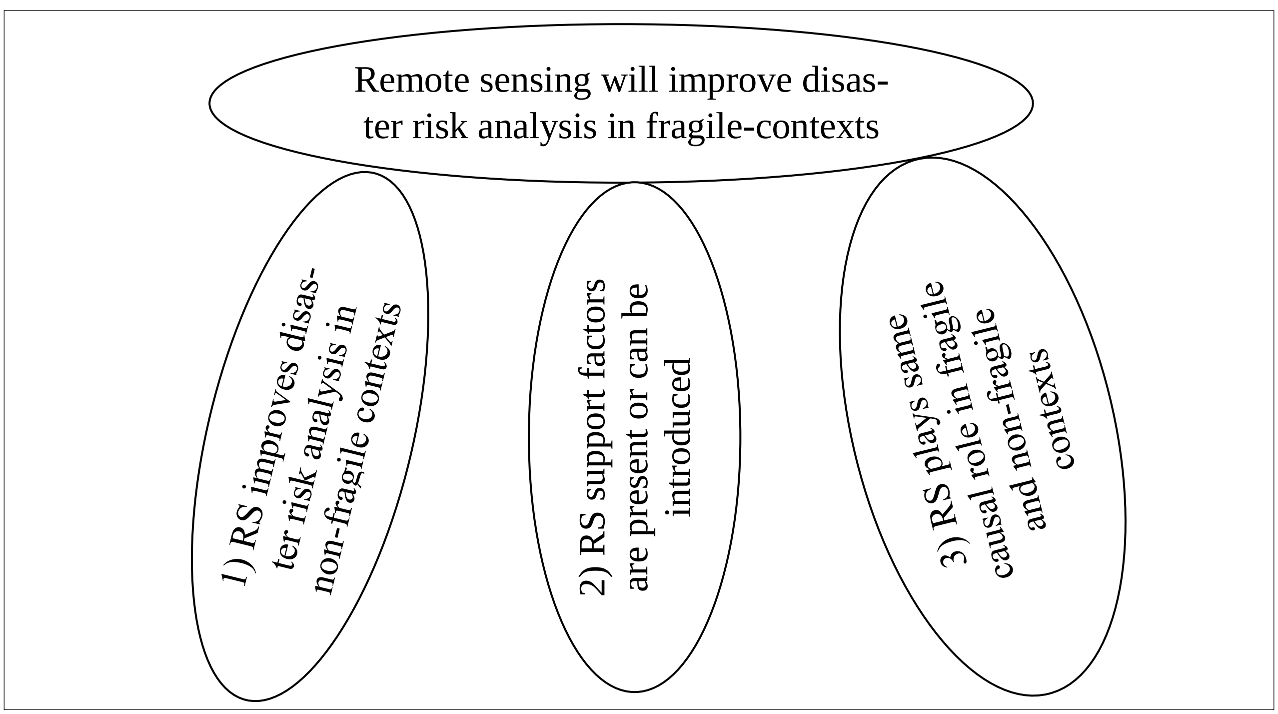
This research applies the perspective of evidence-based policymaking. The central question is whether a policy is effective in a particular context (here) and able to be effective in another context (there) as well. The desired outcome of a policy is to contribute positively to future change. For this reason, it is crucial to assess whether there is enough evidence to make a *robust effectiveness prediction*. The confidence over the claim that a policy works in another context, is based on trustworthy premises and the conclusion is implied by the premises (Cartwright/Hardie: 2012: 3–13). In this work, evidence-based policymaking helps to ask, whether RS is an effective policy to improve disaster risk analyses in fragile contexts as well as it does in non-fragile contexts.

This work identifies causal principles, which fill in the missing premises for fragile contexts. To describe a respective causal principle, there needs to be a reliable, systematic connection between causes and effects (Cartwright/Hardie 2012: 14-15). The final policy advice stems from this theory of evidence: it strives to understand a problem and the necessary kind of knowledge to make reliable predictions about whether the policy improves the targeted outcome as the policymaker would implement it in another context as well. Therefore, policy effectiveness predictions are causal claims that rely on facts (data) from studies and past experience. Thus, the conclusion is an *effectiveness prediction* about which effects RS has for disaster risk analyses in fragile contexts. Ultimately, the aim is to provide evidence-based policy advice for different stakeholders (Cartwright/Hardie 2012: 14–23).

Regarding evidence, this work relies on interviews with twelve experts. The structure of the interview follows the key assumption of evidence-based policymaking: causes are '**I**nsufficient but **N**ecessary part of an **U**nnecessary but **S**ufficient [INUS] condition[s] for producing a contribution to an effect' (Cartwright/Hardie 2012: 25). Accordingly, the present work assesses whether RS is an INUS condition to improve disaster risk analyses in fragile contexts. In theory, to apply the INUS condition, first, the physical presence of RS is **I**nsufficient to produce the desired outcome. However, second, RS needs to be an indispensable ingredient — a **N**ecessary component — of disaster risk analyses. Third, taken together, RS may be **U**nnecessary to improve understanding of disaster risks since a range of other policy options exists, for example household surveys. Fourth, the question is whether all separate components of the RS policy together are **S**ufficient to imply the improvement of disaster risk analyses. Hence, the actual effectiveness prediction of the contribution in a given situation also depends on all other policies under operation. It follows, that RS may contribute differently, positively and negatively, to disaster risk analysis in a given fragile context. The *INUS condition* is particularly useful in the present analysis to underpin that RS can only be part of a contribution for disaster risk analyses. Lastly, the question arises whether crucial *support factors* — staff, budget, etc. — are available for RS to be effective. If they are not available, the question is why and if they can be introduced (Cartwright/Hardie 2012: 25).

Thus, the *effectiveness prediction* in this work is based on three pillars visualized by Figure 1: First, RS plays a positive causal role in a particular context and the support factors necessary for it to play this positive role are present. Second, RS can play the same causal role in a fragile context as well. Third, the support factors necessary for RS to play a positive causal role in the fragile context are in place. Taken together, all three pillars may allow for the conclusion that RS will work in fragile context as well (Cartwright/Hardie 2012: 51–55).

Figure 1: Three Pillars Supporting the Effectiveness Prediction



Own elaboration. Idea for figure taken from (Cartwright/Hardie 2012: 55).

Against this conceptual background, the following null hypothesis (H_0) rejects the effectiveness prediction of RS to improve disaster risk analyses in fragile contexts:

H_0: Remote sensing does not improve disaster risk analyses in fragile contexts.

In turn, the positively formulated hypothesis (H_1) is:

H_1: Remote sensing improves disaster risk analyses in fragile contexts.

Thus, evidence-based policymaking is the foundation for the further course of this analysis.

III. LITERATURE REVIEW — Global Disaster Risk Governance

This section introduces the global disaster risk governance architecture[2]. For a disaster to occur, a number of factors have to be in place: a hazardous event or process as well as so-called *elements at risk* (EaR) that are located in the area *exposed* to the hazard and that are *vulnerable* to the hazard.

> The result is a globally applied risk equation in which disaster risk is a function of a natural hazard, exposure and vulnerability (UNDRR 2019: xii; Wisner et al. 2004).

Disaster risk governance is a system of institutions, mechanisms, policy and legal frameworks to coordinate disaster risk reduction and related areas of policy. Moreover, disaster risk governance forms part of good governance being 'transparent, inclusive, collective and efficient to reduce existing disaster risks and avoid creating new ones' (UNDRR 2020b). Effective disaster risk management is convergent with other policies that aim to reduce risk exposure and vulnerability to avoid or reduce human casualty and economic losses caused by disasters (Ranke 2016: 333). Furthermore, disaster risk governance consists of 'polycentric and multi-level networks with multiple centers of decision-making authority' (Tierney 2012). While governments play a central role in DRR efforts, functions are more dispersed among a diverse set of actors, namely multiple government agencies at all levels as well as the civil society, private sector and non-governmental organizations (Thompson 2019: 70; Tierney 2012). Ideally, all stakeholders collaborate in decision-making for the common goal to reduce disaster risks. In practice, however, risk governance is frag-

[2] Please note, that this chapter introduces DRM-related terminology, which is listed and explained in Annex 2.

mented among multiple actors from the local to the international level as well as within and between sectors and public administrations (Thompson 2019: 66; Tierney 2012: 344). As a result, different stakeholders seek guidance to clarify responsibilities between different governance levels of DRR (Rao 2013). Finally, the high level of transaction costs among multiple governmental, civil society or private entities may inhibit effective disaster risk governance (Thompson 2019: 65).

As a result, international frameworks and institutions aim to provide guidance to advance disaster risk governance. DRR is closely tied to several prominent post-2015 frameworks, namely the 2030 Agenda for Sustainable Development, the Paris Agreement on Climate Change and in particular, the *Sendai Framework for DRR 2015–2030* (UNDRR 2015). All three frameworks hold, that governments need to understand their environment and the efforts to reduce disaster risks, prepare better to manage losses and damages triggered by disasters and plan climate change adaptation and general efforts toward sustainable development (Post et al. 2017: 189). The Sendai Framework is an action-oriented, voluntary framework, which guides member states and relevant stakeholders to improve their disaster resilience for sustainable development while recognizing climate change as one of the drivers of disaster risk. In detail, the Sendai Framework includes seven 'Global Targets' for member states such as 'substantially reduce the number of affected people globally by 2030' and 'reduce direct disaster economic loss' (UNDRR 2015). The Sendai framework further includes four 'Priorities for Action', with the first being the improvement of 'understanding disaster risks'[3] (UNDRR 2015: 14). Generally, risk analyses contribute to the first priority: *understanding disaster risks* in all dimensions of vulnerability, exposure of people and assets and hazard characteristics. Potentially, RS offers multiple potentials to advance on understanding risks, for example by visualizing exposure and multi-hazard characteristics at different spatio-temporal scales (Post et al. 2017: 190).

When it comes to cutting-edge understanding of risks, the United Nations Office for DRR (UNDRR) present the so-called 'Global Risk Assessment Framework' (GRAF). Interestingly, it aims to assess 'systemic vulnerabilities' focusing on the 'interlinkages of multiple risks and actors across systems' (UNDRR 2019: 5). The GRAF aims to understand the multidimensional nature and dynamic interactions of risk to improve the first priority of the Sendai Framework (UNDRR

[3] The second Priority for Action is 'strengthening disaster risk governance to manage disaster risk'; the third 'investing in disaster risk reduction for resilience'; and the fourth 'enhancing disaster preparedness for effective response and to build back better in recovery, rehabilitation and reconstruction' (UNDRR 2015).

2019: 65–68). The GRAF serves as prime example to show that international disaster risk governance is nested and influenced by overarching governance systems (Thompson 2019: 65). Finally, several DRM-policymakers such as the Food and Agriculture Organization (FAO) and German Federal Ministry for Economic Cooperation and Development (BMZ) describe their DRM actions along the so-called 'DRM-Cycle' displayed in Figure 2. The DRM-Cycle illustrates interlinkages between individual stages of DRM — from response to post-disaster phase (rehabilitation and recovery) to pre-disaster phase (prevention and preparedness). It further highlights that DRM is a continuous process that aims to increase resilience at all stages.

Figure 2: The Disaster Risk Management Cycle (DRM-Cycle)

Own elaboration. Source: (Baas/Food and Agriculture Organization of the United Nations 2008: 7; BMZ 2015: 15).

Moreover, disaster risk analysis is foundational for subsequent actions in the DRM-Cycle. Furthermore, the result of the implementation is more sustainable when different stages are linked to each other (BMZ 2015). In case of limited state capacity, lack of national institutions and resources, UN-organizations and non-governmental institutions have assumed responsibility for disaster risk governance (Thompson 2019: 70).

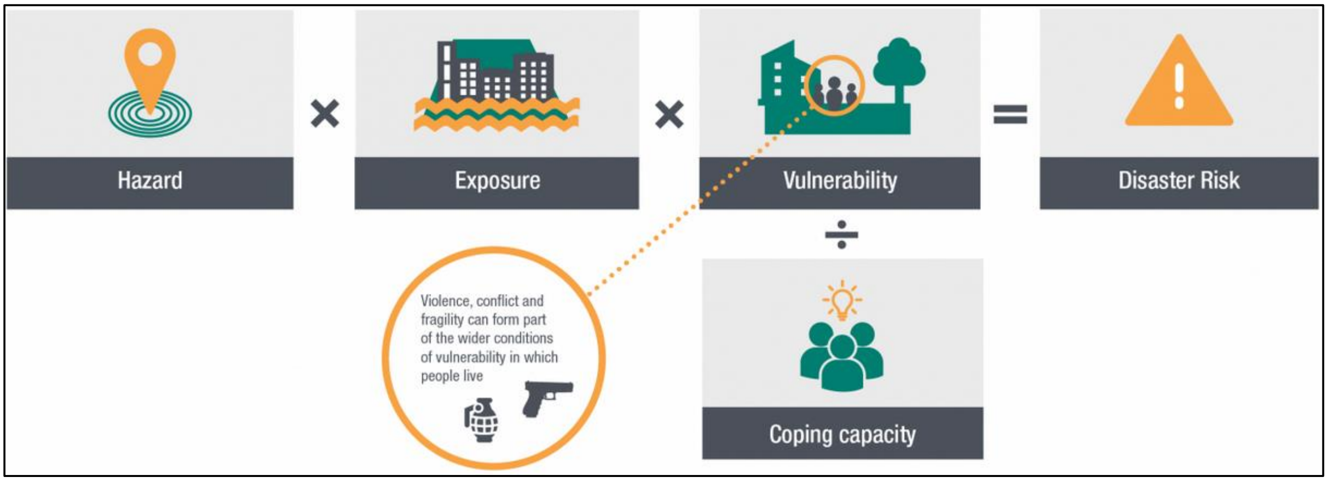
IV. PROBLEM DEFINITION — DRM in Fragile Contexts

This chapter presents the particular challenge of conducting disaster risk analyses in fragile contexts. Every context includes unique sets of multiple interacting risks. At different times within a given context, different combinations of risks become more or less salient (UNDRR 2019: 404). The OECD (2018: 84) defines fragility as 'the combination of exposure to risk and insufficient coping capacity of the state, system and/or communities to manage, absorb or mitigate those risks'. Fragility can lead to negative outcomes including violence, the breakdown of institutions, displacement, humanitarian crises and other emergencies. Violent conflict may take various forms, including interstate war, armed conflict, civil war, political and electoral violence and communal violence. Fragile contexts typically experience widespread violence, political instability, ineffective institutions, insecurity, repression and human rights abuses and violations of international law (ODI 2019: 14; OECD 2018). Tellingly, the share of extreme poor people living in fragile contexts has doubled to over 40 percent between 1990 and 2012 (Shepherd et al. 2017).

Many people live in hazard-prone areas because their circumstances leave them no other choice or because access to economic opportunities outweighs perceptions of hazard risk — for instance refugees living in informal settlements on the edges of cities at risk of landslides. Therefore, disaster impacts are not limited to immediate damages caused by the hazard. Instead, the magnitude of disasters is determined by how the disaster interacts with the pre-existing social, economic and political context. Recent publications on the so-called 'disaster–fragility nexus' highlight that 'disasters are neither natural nor conflict-neutral' (ODI 2019: 17–18). Prominent examples are the earthquake in Haiti in 2010 and the displacement of Rohingya refugees into monsoon affected parts of Cox Bazar, Bangladesh in 2018.

Thus, as Figure 3 shows, disaster risk is a construct: apart from the *hazard*, neither *exposure* (people, assets), nor *vulnerability* and *coping capacity* are politically neutral. Vulnerability refers to individual coping conditions of people and assets to mitigate hazard affects, which depend on physical, psychosocial, cultural, economic, environmental and other preconditions. Therefore, as Figure 3 illustrates, fragility forms part of the wider conditions of vulnerability and has aggravating effects. Beyond the immediate impacts of conflicts, fragility increases vulnerability and exposure to hazards, undermines states' and societies' coping capacities, exacerbates hazard impacts and inhibits effective disaster risk governance (ODI 2019: 14–18).

Figure 3: The Role of Fragility, Conflict and Violence in the Construction of Disaster Risk



Source: (ODI 2019: 16). Please note, definitions of key terms including 'disaster risk', 'hazard', 'exposure', 'vulnerability' and 'coping capacity stem from the UNDRR terminology guidance (2020a-b). Term definitions in Annex 2.

While humanitarian responses to disasters often operate in conditions of fragility, less attention has been paid to adapting disaster risk governance to fragile contexts. The prevention of disasters and conflicts has largely been treated separately, governed by different frameworks and institutions. Given the worldwide prevalence of fragile contexts, this is *not* a marginal problem. It is important to reiterate the fact that disaster risks in fragile contexts are often a politically sensitive issue, e.g. because minorities suffer from discrimination, which affects their vulnerability. A key finding from several case studies is that 'more dedicated support to national disaster management agencies is required to deliver on DRR strategies in ways that are cognizant of issues of fragility, conflict and violence' (ODI 2019: 14–17). Therefore, it is important to highlight the more complex interaction of natural hazard risks, exposure and vulnerability and the respective preconditions. It follows that, in fragile contexts, several needs are magnified and components of the risk equation are more difficult to understand. While risks affect every context in unique ways, similarities in complex systems of risk emerge: the need to address multiple vulnerabilities, particularly considering vulnerable persons and groups[4], to engage long-term across sectors, at multiple levels and to adapt to

[4] Vulnerable groups include Internally Displaced Persons (IDPs), refugees and host communities, women, adolescence, elderly, people who identify as Lesbian, Gay, Bisexual, Transgender, Intersex or Questioning (LGBTIQ+) and

dynamic contexts — primarily meaning that they can change rapidly in unanticipated ways (UNDRR 2019: 412–413).

The disaster–fragility nexus is one of the most pressing issues to address vulnerability. That includes forced migration, human and national insecurity and the impacts of climate change (UNDRR 2019: 414). Moreover, the nexus affects risk-informed development, including long-term concepts such as the so-called 'resilience dividend', which means that economic resources invested in resilience 'pay-off' by saving more economic resources compared to (costly) humanitarian interventions (Lorenzo-Alonso et al. 2019). Thus, there is a need to improve DRR tools and technical frameworks to make them viable for risk-informed development in fragile contexts (ODI 2019: 34).

Finally, fragile contexts are more challenging places to conduct disaster risk analyses. First, because analyses need to address a wide range of intersecting vulnerabilities. Second, because national institutions may not be able or willing to provide a functioning national disaster management system but rely on external humanitarian interventions instead (UNDRR 2019: 413). Third, because DRM policies are politically sensitive — particularly when states are complicit in processes of discrimination and marginalization. Therefore, disaster risk governance potentially lacks institutional capacities, trust and effectiveness. Thus, a key recommendation that follows from the disaster–fragility nexus is to seek interdisciplinary collaboration across the disaster, climate, conflict and peace specialisms. Ultimately, new forms of collaboration contribute to understanding the complexity of DRM in fragile contexts and to explore opportunities for linking DRR and conflict prevention measures (ODI 2019: 41–45).

disabled people and otherwise religiously, ethnically, socioeconomically and geographically marginalized people. In addition, vulnerable groups include large numbers of victims of violence and those at heightened risk of violence (International Federation of Red Cross and Red Crescent Societies 2016; UNDRR 2019: 414).

V. THE POLICY IN QUESTION — Remote Sensing

This section introduces the policy in question, remote sensing (RS). Since situations of complex risks in fragile contexts are inherently dynamic such as the security situation, it alters the ability to effectively design, plan and implement DRR policies. Therefore, RS may become more useful to overcome key constraints linked to fragility (UNDRR 2019: 417).

RS is defined as 'the acquisition of information about an object or phenomenon from a distance without making physical contact' (NASA 2020). More than a hundred RS satellites are in operation to provide measurements from space. They employ a multitude of sensors that detect and record different parts of the electromagnetic spectrum using different techniques. Technically, RS imagery stems from either optical (passive) or microwave or radar (active) sensors. RS provides a global perspective and a wealth of data about different systems, which enables evidence-based decision-making such as by disaster authorities (NASA 2020).

Several developments have taken place over the last five decades since the first civilian use case in the 1970s. Many countries have launched their own satellites, the international RS community has become more connected and a number of RS sensors and methods have become more relevant from a DRM perspective (Thenkabail 2016: 233). Reportedly, the use of a space-based infrastructure for disaster risk analyses provides several potentials: the infrastructure is not vulnerable to the disaster itself (unlike in-situ sensors), information is collected systematically on multiple scales and 'inaccessible and hazardous areas can be sensed without risk' (ESA 2015: 6). These developments have contributed to obtaining knowledge about disasters and to new ways of quantifying risks. Due to its scope and availability, RS — in combination with data analysis — has become a crucial tool for humanitarian and development professionals (Thenkabail 2016: 486). As Figure 4 summarizes, RS potentially addresses several components of the risk equation and the DRM-Cycle.

Figure 4: Risk Equation and DRM Potentials for the Use of RS

Element of Risk Equation/DRM	How RS data contributes to understanding
Risk analysis	• RS cannot directly detect risk, but it can analyze the principal determinants of disaster risk — hazard, exposure and vulnerability
Hazard	• Assessing hazard variation in terms of spatial extent, duration, frequency • Depending on hazard type and RS method, large consequences for the utility of RS data in terms of their spatial and temporal resolutions
Exposure of Element at risk (EaR)	• Assessment of the exposure of EaR, in particular physical ones: ○ High spatial resolution imagery to identify infrastructure elements ○ Systemic elements and their components, other elements (e.g. economic activity) may be detected using proxy indicators
Vulnerability	• Assessing susceptibility to physical injury, harm, damage, or economic loss of different objects such as building types under different scenarios • For non-physical or process vulnerabilities, physical proxies may be extracted from image data (e.g. neighborhoods, road networks, etc.)

Source: own elaboration based on (ESA 2015: 6–11; Thenkabail 2016: 461-462).

Most importantly, it follows from Figure 4, that RS is *not* able to assess disaster risk directly. Accordingly, RS does *not* result in reduced loss and damage, but its application may facilitate evidence-based decision-making that can bring this about (see **I**nsufficient but **N**ecessary in INUS condition). More precisely, RS contributes to different products such as risk assessments and mappings of different hazard types, monitoring and scenario building. Hence, RS can help science in 'narrowing down the uncertainty in disaster risk assessment and support better informed practitioners and end-users' (ESA 2015: 6–11).

Overall, Figure 4 illustrates to what extent RS potentially provides information on the three parameters of the risk equation: First, the hazard analysis predominantly includes monitoring the type, scope and frequency of an existing hazard event (Thenkabail 2016: 462). Second, the mapping of exposure of EaR captures objects that may be adversely affected by hazards. Such EaR are diverse and include physical assets (buildings or infrastructure), places of cultural or natural heritage, national parks and sites of biological diversity. In addition, systems include non-physical elements and processes that may be disrupted by a hazardous event such as cultural diversity, political systems, or economic processes. Third, regarding vulnerability, one focus to date is on physical vulnerability, defining how much damage a given EaR will likely sustain in a specific hazard scenario.

However, as the disaster–fragility nexus shows, vulnerability and coping capacity are more complex social phenomena. Several characteristics make vulnerability assessment particularly challenging: first, vulnerability entails different physical, social, economic and environmental factors; second, vulnerability is dynamic, such as population or building age; third, vulnerability is scale-dependent: it ranges from the individual (building, person, road, etc.) up to community and country level and fourth, vulnerability depends on the hazard type — the same building that might withstand floods might suffer during an earthquake (UNDRR 2020b). This discussion is linked to the limitations of RS. The comprehensive assessment of risks remains a methodological challenge. Although there is a good understanding of the role physical vulnerability plays in the risk equation, social or political vulnerability are rarely captured by traditional approaches. In sum, Figure 5 shows that the RS literature describes different degrees of utility of RS depending on the phases of the DRM cycle and the natural hazards type.

Figure 5: Utility of RS for Different Stages of DRM and Hazard Types

Hazard Type	**Hazard Assessment**	**Prevention/ Mitigation**	**Monitoring/ Early Warning**	**Recovery/ Rehabilitation**
Flood	++	+	+/++	++
Tsunami	-	-	-	++
Storm	+/++	-	++	++
Earthquake	+/++	-	+	++
Drought	++	+	++	+
Volcanic	+/++	-/+	++	+/++
Landslide	++	+	+	-/+
Wild fire	++	+	++	++
Desertification	+	+	+	+
Erosion	+	+	-	+

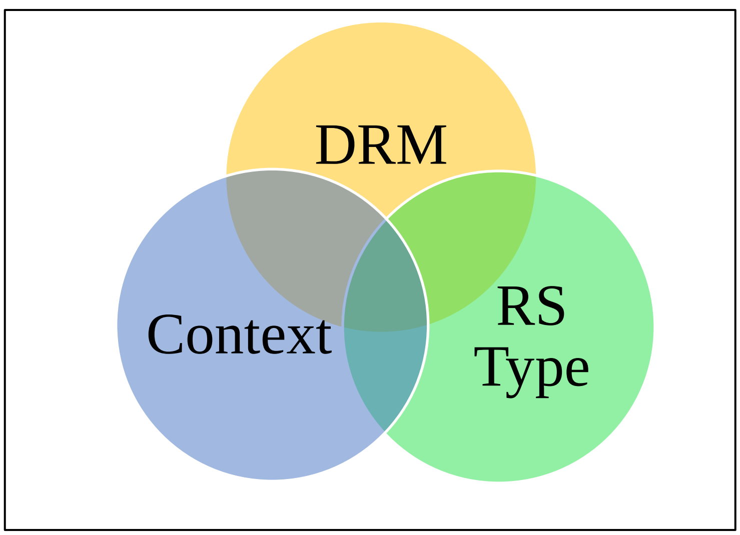
Key: −, limited or no utility; +, moderate utility; ++, high utility. Source: (Thenkabail 2016: 463).

Figure 5 indicates that RS supports a wide range of disaster types and all phases of the DRM-Cycle. A closer look yields that RS has a higher utility when applied to DRM phases close to and after hazard events. This corresponds to the statistic that 90 percent of disaster risk monitoring is attributed to hydrometeorological hazards. In these cases satellite imagery provides a viable option for fast and large-scale analysis of flooded regions (ESA 2015: 62, 69). In contrast, Figure 5 yields a moderate utility of RS at pre-disaster stages. Beyond hazards, RS is employed to capture conflict-related events such as forced migration (Thenkabail 2016: 489-490). Thus, according to the literature, RS is a key source for DRM and humanitarian aid. However, the present work focusses on disaster risk analyses in fragile contexts vis-à-vis latest developments in RS. The initial research shows that fragile contexts are the blind spot of the RS and DRM literature. To fill this gap and to answer the research question, it is crucial to triangulate the literature review. The triangulation method represents a reality check with two components: the examination of publications on RS applications and the empirical analysis of eleven expert interviews.

VI. DESK STUDY — Literature on Remote Sensing Applications

This desk study forms the second part of the triangulation method. It examines the status quo in the literature, mainly primary sources, on RS applications for disaster risk analyses. These publications divide in three clusters: the first focusses on specific stages of DRM and natural hazards, the second addresses particular contexts and the third deals with different types of RS applications. As displayed by Figure 6, two of these clusters overlap in most publications.

Figure 6: Three Clusters of Publications on RS Applications for Disaster Risk Analyses



Source: own elaboration.

When it comes to the first cluster, DRM, the majority of publications deal with disaster risk analyses for a special hazard-type from one of the four major categories: geophysical, meteorological, hydrological and climatological hazards. So far, the most widely-cited publications focus on the geospatial assessment of *floods* (Cilliers 2019; ESA 2015: 20–32; Fekete et al. 2017; Franci et al. 2015, 2016; Halls/Magolan 2019; Imran et al. 2019; Mojaddadi et al. 2017; Rahman/Di 2017) and *earthquakes* (Alizadeh et al. 2018; Davidson 2013; Geiß/Taubenböck 2013, 2017; Yue et al. 2018).

Regarding the second cluster, 'Context', a large amount of publications engages with disaster risk analyses in the most prominent hazard-affected countries or regions, particularly in *Southeast Asia* (Ha et al. 2019; Kaku 2019; Shaw et al. 2016) such as Thailand (Kaiser et al. 2013; Römer et al. 2012; Willroth et al. 2012), Vietnam (Boateng 2012; Dang/Kumar 2017), Nepal (Pangali Sharma et al. 2019), Indonesia (Helmi et al. 2019) and India (Dandapat/Panda 2018; Le Masson 2015; Sahana/Sajjad 2019) and in *Africa* (Ntajal et al. 2017), for instance the Sahel region (Deafalla et al. 2014; Herrmann et al. 2014), Senegal (Diack et al. 2017), Morocco (Jazouli et al. 2019), Egypt (Mohamed/El-Raey 2019), Togo (Ntajal et al. 2017), Namibia (Skakun et al. 2014), Cameroon (Aka et al. 2017), Zimbabwe (Dube et al. 2018; Mavhura 2019), Ethiopia (Asmamaw/Mohammed 2019; Fenta et al. 2019), Rwanda (Mind'je et al. 2019) and DR Congo (Kranz et al. 2018; Michellier et al. 2020) as well as in *Latin America* such as in Colombia (Gallego Perez/Selvaraj 2019; Murad/Pearse 2018) and Chile (Geiß et al. 2017). Context-specific sources further highlight disaster-prone *urban areas* (Alizadeh et al. 2018; Capes/Teeuw 2017; Fekete et al. 2017; Franci et al. 2015; Komolafe et al. 2018; Nero 2017; Salami et al. 2017) and *rural areas* (Christoplos 2010; Dube et al. 2018). Tellingly, urban areas in the developing countries accommodate more than half of the global population and hundreds of billions USD in assets (ESA 2015: 35).

When it comes to the third cluster, 'RS Type', publications cover many technical aspects and intersectoral use cases of geospatial information systems (GIS), ranging from risk analysis for prevention purposes in *international development* (Fekete et al. 2015; Leidig et al. 2016; Lorenzo-Alonso et al. 2019; Post et al. 2017; Wu et al. 2018) to ex-post assessments and emergency mappings in *humanitarian aid* (Lang et al. 2019; Chaudhri et al. 2019). RS technologies have made immense progress over the last decade, nowadays offering services from all sensor types, ultra-high-resolution up to a few centimeters per pixel as well as enhanced data selection and processing with machine learning. Therefore, RS applications increased within the humanitarian aid sector at an unprecedented rate over the last decade, enabling fast and detailed information such as for early warning systems. Thus, multiple RS techniques have become an essential component of disaster risk analyses in different sectors (Lang et al. 2018).

Furthermore, several multilateral institutions support the access and the use of RS, namely the UN Office for the Coordination of Humanitarian Affairs (UN OCHA) (Jensen et al. 2015), the UN Platform for Space-based Information for Disaster Management and Emergency Response (UN-

SPIDER) including the SPEAR program[5], the UN Office for Outer Space Affairs (UNOOSA) (Post et al. 2017), the World Bank, the Asian Development Bank and the European Commissions' Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) and the European Space Agency (ESA) with the joint program Earth Observation for Sustainable Development (EO4SD) (Lorenzo-Alonso et al. 2019).

When it comes to international RS mechanisms, Figure 7 illustrates that crisis mapping is regulated at the international level by the International Charter Space and Major Disasters, initiated in 2000 by the National Centre for Space Studies and the ESA (Fekete et al. 2015). The protocols provide for data acquisition on a priority basis and draw on the space assets of virtually all space agencies and private companies (Thenkabail 2016: 471-476). The Charter facilitated the use of RS data in well over 110 countries for over 400 natural and technological hazards between the years 2000 and 2015. In 70 percent of the cases the Charter has been activated for weather-related disasters, whereas earthquakes and volcanic eruptions represent 20 percent of Charter activations (ESA 2015: 42–43).

Furthermore, the Copernicus Emergency Management Service (CEMS) is the European system for earth observation managed by the European Commission. Since 2012, it provides maps and analyses based on satellite imagery (before, during and after disasters) and early warning services for multiple hazards. In practice, as Figure 7 highlights, these two major services largely differ from each other. As the only regional program worldwide, the Copernicus program includes both an emergency and a 'non-rush risk and recovery' mode. The latter mode records and increases in demand because it adapts closer to the end-users needs to assess the relevant components of the risk equation and to conduct more comprehensive risk assessments such as for prevention purposes (European Commission 2020).

[5] Space based Earth observation Applications for Emergency Response and Disaster Risk Reduction (SPEAR) Program: https://www.zfl.uni-bonn.de/research/projects/spear .

Figure 7: Overview of RS Disaster Initiatives, Services and Specificities

Disaster Initiative by Agency	Type of Service or Data	Aim/ Specificities
International Charter on Space and Major Disasters (24/7 operational service)	Satellite-based data and information during major natural or man-made disasters	• Free of charge for authorized users • For major natural disasters • Not for conflict regions or humanitarian crisis situations
Copernicus Emergency Management Service (CEMS) *Rush mode*: Delivery in hours/ days *Non-rush mode*: Delivery in weeks/ months	Geospatial information from RS, open data after activation in the course of natural or man-made disasters, humanitarian crises and risk analysis • *Rush 'emergency' mode*: standardized products - reference maps, delineation and grading maps • *Non-rush 'risk and recovery' mode*: end-user needs based products - disaster risk analysis for all DRM phases (reference maps, pre- and post- disaster situation maps)	• Service paid by EU member states • Not for conflict regions and limited with respect to humanitarian crisis situations • "Security service" potentially toward services for conflict and humanitarian situations • Existing data free of charge for users, results publicly available at http://emergency.copernicus.eu/mapping/

Source: own elaboration based on (European Commission 2020; Thenkabail 2016: 461-462).

In line with the development of the CEMS, the European Commission together with the ESA incrementally launched its own constellation of satellites — the Sentinels (Sentinel 1, 2, 3, 4, 5P, 5, 6) to provide robust datasets for all services. Finally, coming to the key aspect of this analysis, many publications combine at least two clusters displayed in Figure 6. Two of the most widely cited publications on the use of RS in fragile contexts focus on impact observation of ongoing armed conflict such as by examining light emission at night in Yemen (Jiang et al. 2017) and IDP camp evolution in Sudan (Lang et al. 2010); however, leaving out disaster risk analyses. A second body of primary sources applies RS techniques to conduct disaster risk analyses such as in Pakistan (Rafiq et al. 2010) and Nigeria (Joseph et al. 2018); but excludes fragility. The latest contribution on the 'DRM – fragility nexus' comes from the Overseas Development Institute (ODI 2019), which, however, excludes RS applications.

Most importantly, a decent amount of publications has emerged which combines *all three clusters* displayed in Figure 6: RS for disaster risk analyses in fragile contexts. One of the first studies to assess 'civil conflict sensitivity to growing-season drought on global scale' with RS techniques was published in 2016 (von Uexkull et al. 2016). Subsequently, other key studies emerged using a so-called 'integrated approach' with regard to drought vulnerability in Syria, Iraq and Turkey (Eklund/Thompson 2017), the Syrian refugee crisis in Lebanon (Pollock et al. 2019) and vulnerability to volcanic risk in the DR Congo (Michellier et al. 2020). One of the most promising contributions comes from the National Aeronautics and Space Administration (NASA) Earth Science Disasters Program which published a case study on the Rohingya refugee camp in Cox Bazar, Bangladesh (NASA 2019: 14). In detail, NASA established partnerships with the Columbia University and the Inter-Sector Coordination Group for Cox Bazar, which includes the UN Development Program (UNDP), the UN High Commissioner for Refugees (UNHCR) and Mercy Corps. Their goal was to bridge traditional professional and disciplinary boundaries to learn more about decision-making in vulnerable contexts. The study aimed to work alongside humanitarian experts and to develop products that address pressing end-user needs in vulnerable settings. It resulted that camp managers and other local officials overseeing Rohingya refugee camps in Bangladesh incorporated RS data into their decision-making to reduce the refugees' risk vis-à-vis landslides and other natural hazards. The NASA-led team is co-developing the information with the Inter-Sector Coordination Group through the *Connecting Earth Observations to Decision Makers for Preparedness Actions* project. Moreover, these stakeholders claim that their partnership could serve as a template for future science-driven data development and integration for humanitarian efforts in fragile contexts (NASA 2019)[6]. Finally, another prominent topic is the use of open-source data, but particularly the need for cloudless, high resolution data, time constraints and expert know-how ensures the high demand for institutional and private services (Elia et al. 2018; Fekete et al. 2015; Goldblatt et al. 2020; Thenkabail 2016).

In sum, RS provides a wide range of valuable information that is pertinent to disaster risk analyses. The majority of publications describe an RS application that has been tailored to a specific DRM-

[6] NASA provides more detailed information on this project in their blog entry from November 19, 2019, see URL: https://www.nasa.gov/feature/nasa-data-helps-assess-landslide-risk-in-rohingya-refugee-camps .

purpose, Context or RS Type. Furthermore, the literature describes more humanitarian RS applications than in the development sector, such as hazard monitoring and response. Some RS publications, however, highlight capabilities for each phase of DRM (ESA 2015: 59–72). Regarding the risk equation, the literature indicates an imbalance of RS applications, assessing more hazards, but less exposure and vulnerability. In contrast, many publications from different communities advocate for the expansion and transfer of RS technology and methods. Although posing one of the most pressing challenges for DRM and risk-informed development, the disaster–fragility nexus and its implications for the use of RS are only recently emerging in the literature. The findings of the desk study underline the need to complement the picture with a broad range of experts from different communities of practice.

VII. EXPERT INTERVIEWS — Thematic Analysis

The following empirical analysis forms the third part of the triangulation method. The collected information is crosschecked through multiple sources to increase the robustness of key findings. The qualitative data stems from eleven interviews[7] with twelve experts from seven leading national and international institutions. Figure 8 provides an overview about the interviewed experts and their professional perspective. The selection of experts was guided by institutional and thematic diversity. The United Nations (UNOCHA/UNEP JEU, UN-SPIDER) represent the multilateral policy level, the German Development Agency (GIZ) different policy levels, both national aerospace agencies (DLR, NASA) and Civil Protection Office (BBK) the national policy level and MAXAR the private sector. All experts cover a wide range of professional perspectives including international development, humanitarian aid, DRM, digitalization and RS.

[7] The eleven expert interviews include ten one-to-one interviews and one one-to-two interview (I.9).

Figure 8: Overview of Expert Interviews

Interview	Institution
I. 1	Joint Environment Unit (JEU) of UNEP/UNOCHA
I. 2	German Corporation for International Cooperation GmbH (GIZ), RS End-user
I. 3	German Aerospace Agency (DLR), Space Project Management
I. 4	UN Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER)
I. 5	German Federal Office for Civil Protection and Disaster Assistance (BBK)
I. 6	GIZ, Global Project FAIR Forward, Artificial Intelligence for All
I. 7	GIZ, Sectoral Department, Competence Center Digital Society
I. 8	NASA, DRR & Resilience and Partnership Management
I. 9	GIZ, Sector Project Peace and Security, Disaster Risk Management
I. 10	Maxar Technologies, Sustainable Development Practice
I. 11	DLR, Earth Observation Center, Geo-Risks and Civil Security

Source: own elaboration.

All interviews followed the semi-structured approach and were conducted via Skype or telephone. Therefore, each interview was guided by six open-ended questions, which allowed for flexibility and in-depth answers according to the experts' expertise. In a nutshell, the questionnaire (see Annex 1) covered: first, the problem of conducting disaster risk analyses in fragile contexts, second, the role of RS as potential solution, third, limitations of RS, fourth, circumstances, supporting and inhibiting factors, fifth, institutional trade-offs and decision-making procedures and sixth, positive and negative examples. Next, the interviews were transcribed into matrices, matching the interviewees' answers to the questionnaire. This is the starting point of the thematic analysis, which focuses on recurring themes across all interviews. Therefore, the empirical analysis relies on many different responses. Several quotes illustrate the leading narratives and the thematic spectrum. In practice, the thematic analysis describes a process of data familiarization, coding and the development of key themes (Braun/Clarke 2006). All key themes capture patterns among responses and contribute to the key findings, the discussion and policy recommendations.

Overall, the thematic analysis follows the structure of the interview questionnaire. In general, each section of the thematic analysis is divided in three parts. First, the spectrum of themes is introduced following the frequency of how many experts put the theme forward. The second part describes themes and key arguments individually, highlighting the most important similarities and differences. Third, the section ends with a short reflection of related themes. Themes and sub-themes are introduced in *italics*; subsequent theme-titles are written in **bold**.

1. Section: Problems to Conduct Disaster Risk Analyses in Fragile Contexts

The thematic analysis begins with the experts' view on problems to conduct disaster risk analyses in fragile contexts. Overall, all experts agree that disaster risk analyses are more difficult to conduct in fragile contexts compared to non-fragile contexts. The spectrum of themes includes *access*, *governance*, *data availability and quality* as well as the *risk equation*.

1. Access. The majority of experts describe problems linked to *access*, for example due to 'the presence of militias, warlords and human rights violations in conflict environments' (I.11). It follows that the resulting lack of security and costs for (potential) countermeasures exceed the limit of organizations to 'send folks on the ground' (I.10). Therefore, most experts highlight at least one of the three subthemes, restricted *field access*, *access to information* and *access to functioning structures and institutions*. It is important to note that each sub-theme involves different local to international stakeholders, which are affected by the restrictions.

2. Governance. The second theme summarizes '*governance* problems in fragile contexts' (I.11). As one expert puts it: 'one of the biggest challenges you will find is, whether the government in a fragile state is really interested in risk analyses or whether it has to solve more pressing problems of governance and social unrests before looking into risks related to natural hazards' (I.4). Hence, 'the political situation and list of priorities looks different' (I.6). Consequently, fragile contexts lack the 'access to and functioning of structures' (I.5,7), 'which are normally responsible and now disrupted […] such as the public administration for cartography' (I.7). Moreover, fragile contexts are described as deficient in the sense that they have 'scarce resources to compile data' (I.4,11) and 'less expertise' (I.3) available for risk analysis methods. Finally, RS is widely perceived as a 'black box which leads to less acceptance' (I.3).

3. Data availability and quality. The third problem complex gains particular importance in light of the 'pressing needs to acquire information for risk analysis' (I.5) such as 'targeting humanitarian interventions' (I.1) or addressing 'disaster prevention and preparedness' (I.2). One interviewee even highlights *data availability* as the 'biggest problem in fragile contexts' (I.7). In terms of *data quality*, the available data may 'not be up-to-date and unreliable' (I.3) such as data on 'population distribution' (I.7). Furthermore, the available data may be 'heterogeneous and not complementary' (I.5) to data from other institutions. One of the main consequences in case of restricted *access* and *data availability* are 'restricted opportunities for validation of data with ground control […], which increase the potential for errors' (I.3).

4. Risk equation. Several answers concern the more complex challenges in understanding the disaster *risk equation*. In broader terms, two interviewees describe the increase in *complexity* due to an 'overlap of political and social conflicts with natural disasters' (I. 11) and 'interconnected problems such as conflict and displacement and significant additional risks' (I.1). With regard to the single components of the *risk equation*, one expert emphasizes that 'the problem is with vulnerability; vulnerability is an absolute mystery' (I.8). One reason for this is that 'many people have not really worked in the humanitarian context, they don't understand the way certain services are provided to communities', for example how 'communities are made vulnerable due to gender dimensions in the particular context' (I.8).

To reflect on the first section, patterns of themes and arguments speak for an interdisciplinary problem awareness. Furthermore, some experts link the difficulty to conduct risk analysis to their own (staff) expertise with humanitarian contexts and general limits of understanding components of the *risk equation*. A final remark on the relationship among themes is that all four relate to each other in different ways — e.g. field access being conditional for other themes.

2. Section: The Role of Remote Sensing as a Solution

The second section summarizes themes from the experts' arguments related to the role of RS as a solution to improve disaster risk analyses in fragile contexts. Four themes emerge from the experts' responses: *functionality*, *complementation*, *risk equation and DRM-Cycle* and *data availability and quality*.

1. Functionality. The first theme captures arguments related to different *functions*, applications and requirements. All experts highlight different unique and beneficial functions related to RS. Some experts consider RS as a 'no-regret approach' or something that 'can do no harm', for example in 'short-term climate change adaptation projects' (I.1). In other words: 'there is no reason against employing RS' (I.6). Moreover, RS 'has huge potential to bypass issues such as access to particular situations […] and broad coverage with limited resources' (I.1). In detail, several experts emphasize the *scope* of RS, namely being able to 'target a broader area' (I.1,2). Regarding end-users needs, RS is ‘useful for national DRM agencies […] to assess how many people and assets are affected’ (I. 3). Another advantage is that RS is scalable ‘from high-tech to barrier free’ (I.9). Thus, regarding *access to information* in ‘fragile contexts, RS is an even more important tool in the toolkit if there is no on-the-ground knowledge’ (I.10). However, applications also require ‘national buy-in’ (I.5) for RS to generate a positive impact in the context.

2. Complementation. The second theme summarizes arguments regarding data *complementation*. ‘Normally’, as one interviewee explains, ‘you have a combination of different methods such as RS for broad analysis, targeted sampling and social research methods to validate information’ (I.1). Interestingly, many experts underline complementation for *validation* purposes. Therefore, RS ‘is no stand-alone tool for all sectors […] you need in-situ data for calibration or interpretation purposes’ (I.7). As a result, several experts highlight that the ‘risk analysis is not complete as long as you have not conducted an in-situ analysis as well’ (I.4) or complemented RS data ‘with own statistical data’ (I.5). Named alternatives to RS include ‘citizen science, social media and local data collection’ (I.1) and ‘mobility data from mobile providers’ (I.7). Furthermore, ‘open source and open data are an enormous factor’. However, the analysis requires ‘even more expertise in case of machine learning and AI for geospatial data’ (I.6).

3. Risk equation and DRM-Cycle. One expert grades the potential of RS for the *risk equation*: ‘A+ for hazard observation, because we understand their movements, impacted areas, trajectory models and impact scenarios quite well; […] B for exposure, because we are getting better but we are not quite there, for example in terms of connectivity to markets […] and vulnerability is the largest missing link in our ability to understand the intersection of risk reduction, conflict and fragile states and remote sensing’ (I.8). In terms of exposure, one expert emphasizes that ‘tracking change of exposure over time is *only* doable with RS, because there are not enough services on the ground’ (I.4). In contrast, regarding vulnerability, another opinion is that RS data only display its strength if other (socioeconomic or census) data is available (I.5). Other experts add that it is possible to assess exposition and vulnerability with RS (I.3,9), although it is ‘objective and limited at the same time, but it helps’ (I.3). Regarding the DRM-Cycle, one expert states that ‘response is — unfortunately — the most visible […] RS is high in demand after disasters for a first image of the situation’ (I.11). Beyond response, ‘it is also important to look at slow-onset events and prevention and employ more risk mapping, which is less attractive for the media’ (I.11). Accordingly, another interviewee mentions that ‘prevention needs to be prioritized if there is no acute danger’ (I.6). In terms of prevention, the ‘potential is far from exhausted’ and one reason for the imbalance in the DRM-Cycle is that ‘workflows and procedural steps for disaster response and emergency mapping are more established’ (I.5). The latter point corresponds to the view of an end-user of RS data who says that he works in the ‘quiet part of the cycle’ dealing with ‘long-term measurements to derive prevention and risk reduction measures’ (I.2).

4. Data availability and quality. RS is seen as direct contribution to improve *data availability*, for example as a ‘first indication if not other information is available, to overcome regional data scarcity’ (I.5). Furthermore, RS data ‘tackles data heterogeneity and builds common ground, complementing statistical models’ (I.5). Another expert highlights the *objectivity* and *reliability* of RS: ‘RS provides a fairly unbiased, consistent input across all fragile areas […], a reliable source of information’ (I.10). The private sector further addresses quality and use of their products: ‘we as provider of imagery tend to focus on making sure that the imagery is at the best quality possible to downstream and enable more improved analyses’ (I.10). Since ‘data can be foundational for both, humanitarians and development practitioners, we have some multi-stakeholder projects’ (I.10). Finally, another ‘challenge is to develop robust methods for wide area coverage with not very high resolution from RS and to ensure computing power’ (I.3).

A brief reflection of this section yields that several experts assign different advantages and expectations to RS as part of the solution. Depending on the context, a unique bundle of advantages may evolve. Interestingly, some experts assume pre-existing institutional capacities to analyze data. Finally, some themes have proven more controversial such as the potential to shed light on the risk equation, particularly vulnerability.

3. Section: Limitations of Remote Sensing

The third section introduces themes related to the limitations of RS for disaster risk analyses in fragile contexts. Four themes emerge from the experts’ responses: *Do-No-Harm*, *data availability and quality*, *governance*, as well as *risk equation and the DRM-Cycle*.

1. Do-No-Harm[8]. This theme describes the potential of RS to cause *harm* and *unintended negative impacts* (UNI)[9]. In general, 'RS data can cause extreme negative consequences in fragile contexts' (I.6). In other words: 'we have to remember that there is a life connected to the end' (I.8). This underlines the metaphor of RS as a 'double-edged sword' (I.9). Subsequently, many interviewees highlight the need to consider Do-No-Harm in case of RS application in fragile contexts (I.8-11). Furthermore, 'there is a multitude of ways RS can be used inappropriately for incorrect purposes, depending on the context' (I.9). One way is that in 'political conflict situations it matters with whom you share data' — for example if 'they [RS data] go into hand of terrorists' (I.9). In addition, in 'autocratic or failed states, RS might not be allowed, because there is no state capacity or the data seems to undermine the state capacity, weakening the reputation [of authorities]' (I.9). Since RS data may reveal '(militarily) sensitive' (I.2,6,11) information, RS data may be a 'security concern' (I.2) and 'people in power see it as an espionage tool' (I.2). Other experts highlight that the 'areas are observed by stakeholders who do not live there' (I.5). Hence, a particular challenge in the context can 'extend our understanding of good and bad' (I.8) — for example because 'we don't know all the potential use cases yet' (I.10). As countermeasures, three subthemes *contextualization*, *localization* and *cooperation* evolve from the experts' answers. First, 'we need to recognize the context on the ground, pulling in field experts familiar with context' (I.8,10). Second, it is 'mission critical to work with local partners to get the ground truth' (I.8). One aim is to 'know the way the data is generated, used and developed with the communities' (I.8). Lastly, organizations have to ensure a 'trustworthy handling of information […] involving different stakeholders, under UN mandate, to mitigate unintended negative impacts' (I.9).

2. Data availability and quality. The guiding question of this theme is 'how accurate and representative is the analysis of the ground truth?' (I.10). On one side, this question underlies pragmatic constraints such as 'cloud cover, satellite availability, legal and political frameworks' (I.6). In comparison to 'in-situ analysis you lose some accuracy but you win in scope' (I.2). On the other side, most experts underline the 'restricted opportunity in fragile contexts for validation and ground

[8] The Do-No-Harm (DNH) concept developed by Mary B. Anderson (1999) analyzes interactions between the conflict context and project interventions. The aim is to neutralize or reduce factors that aggravate conflicts and to strengthen factors that support non-violent conflict resolution. DNH is an important instrument for improving conflict-sensitive planning and implementation of interventions being an integral part of approaches to crisis prevention. DNH raises awareness of the positive and negative effects of the intervening parties' own behavior in conflict situations and includes lessons learned from negative experiences of humanitarian aid. DNH is mainly used for projects that do not directly deal with the conflict but want to react sensitively to it ("working *in* conflict") (Welthungerhilfe 2007: 8).

[9] This term is borrowed from the GIZ Safeguards and Gender Management System (giz 2020).

control of RS data with in-situ surveys' (I.3). In practice, however, 'many RS applications require in-situ data for calibration and interpretation purposes' (I.7). If this *complementation* is not possible — due to restricted *access* and *data scarcity* — the potential negative results are 'uncertainty' (I.9) and greater potential for 'type one and type two errors' (I.3,10). Next, the question arises 'how to life with uncertainty?', which highlights the 'need for transparent communication of shortcomings' (I.9). This is again, where the sub-themes *contextualization*, *localization* and *cooperation* come into play: 'the partner selection may be limited but someone is always there […], you need to look for civil society and religious structures, community-based organizations and UN organizations such as the WHO' (I.9). Moreover, even if data is available, limitations may arise such as: 'selection, analytical and reporting biases', because analysts 'need experience to know how something looks like from space […] so organizations hire externals, mostly with military and intelligence backgrounds, which are inclined to look for heavy weaponry […], that leads to a "coloring" of the analysis' (I.6). In addition, it matters 'for whom you do the analysis […] for example for NGO's, who need easy to read imagery for donors […] and disaster risk is hard to display' (I.6).

3. Governance. The third theme captures limitations related to *governance* challenges for RS in fragile contexts. Lessons from the first section (problems) apply here as well: generally, 'it is more difficult to work with governments' (I.11) — for example due to a 'lack of interest' (I.4) and a 'lack of awareness that RS is useful for their purposes' (I.6). Furthermore, 'analytical capacity is concentrated in a few areas' (I.6) and 'local resources are limited' (I.4). These challenges come on top of dealing with the 'national bureaucracy and political acceptance […] and make capacity building in principle more difficult' (I.7). Thus, it is for example not possible to 'embed an earth observation center politically and in the public administration' (I.7).

4. Risk equation and DRM-Cycle. The limitations of RS directly relate to the *risk equation and the DRM-Cycle*. The general aim, following *Do-No-Harm*, is to 'avoid putting people in greater situations of vulnerability and exposure' (I.8). Furthermore, to avoid the 'incorrect measurement of vulnerability and minimize uncertainty […] there is a need for complementation with other instruments to get the risk equation right and validate locally' (I.9). One restriction is that with RS 'you cannot measure social cohesion or financial resources', but 'the complementary use of proxy indicators is ok' (I.9). Moreover, as one expert clarifies 'the one part of the risk equation we cannot see from satellites is the vulnerability: it is very social and very hard to see, even in fantastically developed countries you can hardly say what the vulnerability of a building is from looking at the roof' (I.4). RS does not allow measuring 'the root causes and dynamic factors' such as 'the progression of poverty in rural areas […] or large social phenomena such as rural-urban migration' (I.4). In addition, 'you need to be very careful with the use of proxy indicators' for instance deriving 'some vulnerability from the exposure of urban settlements' (I.4). Again, there is the call for 'in-situ surveys, to understand the vulnerability side, whatever the root causes are' (I.4).

Briefly reflecting on this section, experts claim different limitations of RS and that their understanding is crucial to avoid harm. Interestingly, the majority of experts deal with several limitations such as *Do-No-Harm* and *unintended negative impacts* across professional disciplines and sectors. More controversial issues include, again, vulnerability and the use of proxy indicators.

4. Section: Circumstances — Supporting and Inhibiting Factors

In the fourth section, the two guiding themes are *support factors* and *inhibiting factors* for the use of RS. Sub-themes regarding support factors include *basic requirements and integration*. In contrast — apart from the absence and deterioration of support factors — inhibiting factors include *complexity and dependencies.*

1. Support factors. Most experts highlight *support factors* for different stakeholders on the supply and demand side of RS applications. On the demand side, there are users from different international organizations, NGO's and public administrations, whereas on the supply side, there are private companies, national aerospace agencies and other international organizations. For the demand side, experts highlight, that users need to 'fulfil basic requirements first' (I.5) or to comply with 'a minimal strength in the institution […] before working with RS' (I.4). Concretely, *basic requirements* include the 'interest of national institutions in RS' (I.4) and 'the acceptance and expertise of methods' (I.3). Next, RS requires 'stability and some institutional resources in place' (I.4). In turn, resources are broadly defined as: 'partner capacities' (I.1), 'budget and know-how' (I.5), 'electricity and internet' (I.4), 'computing power […] and national legislation for the use of information' (I.3) as well as 'access to and sharing of data' (I.9) to 'validate RS data on the ground' (I.3).

On the supply side, interviewees underline the need for special *expertise and integration* of approaches. The argument begins with organizational 'know-how to process existing (open) data […]

and agency to show the added value of RS data' (I.5). This requires 'transparency and documentation […] to show how the data is generated' (I.5). One RS end-user stresses the direct communication with partner institutions about the 'quantity of data points […], the time frame […], accuracy […], assessment methods […] and results' (I.2). Moreover, another expert emphasizes, 'there needs to be 'more intersectoral thinking and connectivity […], looking at multiple disciplines' (I.8). Concretely, this requires integrating 'longer term strategic planning of the agency or organizations deciding on the ground and data providers' (I.8). Indeed, development experts claim that capacity building and 'investments for prevention and the resilience-dividend are a good topic for international development organizations, taking over initial costs and improving prerequisite to generate benefit in the long run' (I.9).

2. Inhibiting factors. The theme *inhibiting factors* includes more than the absence or the contrary of support factors. RS is described as 'inherently complex' (I.3), 'resource intense, including high costs, expertise, staff and capacities dealing with high-tech and the translation of information to the end-user […], which implies many intermediate steps in the provider-user relationship' (I.9). Two practical factors are scope and time, because 'covering a large area with high-quality data is unrealistic' (I.3). In terms of supply, 'there are too many data and platforms and private companies'. Beyond *complexity*, *dependencies* inhibit the use of RS such as in the 'humanitarian sphere which relies on UNOOSA and their data production […], which is one entity for a number of crises in the world' (I.8). In contrast, on the demand side, constraints such as the 'sensitivity and politicization of data' may lead to the fact that 'RS data may not be seen as an objective measure of reality' (I.5). Within the institution, 'unclear hierarchies, high turn-over rates of personal, data heterogeneity and corruption' (I.5) may inhibit the (appropriate) use of RS.

Briefly reflecting on this section, all experts underline different sets of factors, which support and/or inhibit the application of RS. In practice, it is hard to know which factors play which role in the context, e.g. which factors turn out to be essential, optional or easier to introduce or mitigate than others. Concrete examples summarized in section six complement the picture.

5. Section: Organizational Trade-Offs and Decision-Making Procedures

The fifth section captures narratives regarding organizational trade-offs and decision-making procedures concerning the use of RS applications. The most relevant themes are *internal* and *external procedures, silo-thinking and transaction costs*[10].

1. Internal procedures. In general, decisions in 'emergencies differ from decisions in projects' (I. 1). In case of emergencies, the JEU relies on their 'network and request activation of UNOSAT, which asks for a concrete product in their catalogue' (I.1). In case of an ongoing project, the JEU 'thinks more about resource allocations, national consultancies and sending own staff' (I.1). Therefore, 'development projects involve higher costs' (I.1). Next, an expert from the DLR highlights that 'the great governance challenge is the transition from project-based progress to sustainable long-term oriented structures' (I.3). Most interviewed experts work with several development projects and institutions. An expert from the GIZ underlines that 'decision-making procedures are very context-specific and any project needs to be oriented at partner interests' (I.7). Furthermore, 'project leaders decide whether they want to accept and work with higher uncertainties if ground-truthing is not possible' (I.7). The expert from NASA emphasizes two additional factors, which influence decision-making, namely staff *expertise* and *cooperation*: 'we are not enough interdisciplinary people in the team — mostly data scientists […] so I build partnerships' such as for validation purposes (I.8). An advantage of working without a 'formal program is that we have inherent flexibility to adapt to changing circumstances' (I.8). In contrast, a DLR expert highlights *compliance* with 'standardized, ISO-certified processes to guarantee quality control […], the four-eye principle […], humanitarian principles and operational guidelines' (I.11). Furthermore, for Maxar, working with 'sensitive data' requires a 'commitment to privacy and transparency' (I.10). Finally, two experts mention intra-organizational resistance versus RS, due to a lack of awareness for particular problems, benefits and use cases (I.5) and due to the potentially harmful misuse of data (I.9).

2. External procedures. Several *external procedures* influence decision-making. First, *regulations,* such as by the USA, which 'regulate RS the same way as military equipment, so we have to down-sample very high resolution', which leads to the question of 'regulation and innovation' (I.10). Second, in case of one Copernicus activation for the GIZ, the process involved several *intermediate steps and stakeholders*, including the GIZ, BBK, CEMS and 'outsourced firms as well

[10] Organization names are spelled out in this section, to enable the follow-up of organizational decision-making.

as sub-contracted experts' (I.2). Third, in terms of *political interest*, topics like 'prevention and mitigation' (I.11) or the 'resilience-dividend are hard to sell' (I.9). Therefore, it is necessary to showcase that 'an RS activation is not an end in itself […] and pays of financially, saving money for in-situ data and organizationally, gaining time, transparency and efficiency' (I.5). This is where UNSPIDER comes into play, with the 'aim to raise awareness for what can be done with RS and point to those who could provide that type of service' (I.4). Therefore, partners, including 'finance ministers […] need to assign a proper value to the cost of data […] and know the return of investment into risk analysis and prevention' (I.4).

3. Silo-thinking and transaction costs. Finally, this theme combines different arguments about the interaction of stakeholders. One expert criticizes: 'there is no larger learning' (I.8) — for example, 'RS can support decisions on the ground but the capacity to understand what is good or bad is not often there in the field […] and from a programming perspective, they are not thinking on a resilience lense; long-term planning objectives, that better integrate these considerations from the beginning' (I.8). Furthermore, 'community silo-thinking prevails […] the RS community highlights technical advantages, whereas the development community focusses particular use cases' (I.3). An additional constraint is the 'lifespan of satellites and the continuation of service delivery' (I.3). Another expert highlights the humanitarian perspective: 'working under time constraints for response […] we require quick and dirty indication of big things in conflict situations' (I.1). In contrast, the development experts claim the 'need for initial investments in prevention, not only response' (I.9). The Maxar-expert adds that 'markets tend to be very silo-ed in kind of a sectoral focus', which leads to the 'classic public-private sector divide, with privates beholden to shareholders and NGO's beholden to donors' (I.10). One underlying reason is that 'high transaction costs de-incentivize people from staying involved' (I.10). Moreover, this argument 'extends to bilateral and multilateral organizations, who have a lot of capacity, but are still not well equipped in a lot of cases to negotiate with tech-companies and data providers' (I.10).

To reflect on this section, several experts show awareness for *silo-thinking and transaction costs* as well as inherent potentials of RS to improve this concern. All experts have put forward different sets of elements, which affect organizational trade-offs and decision-making. To see how these considerations turn out in practice, the analysis moves on to concrete examples.

6. Section: Examples — Experts' Good Practices and Challenges

Figure 9 illustrates the final section on examples, which experts describe as good practice (green), critical situation (yellow) or challenge (red). These cases stem either from their own professional experience or from the experience of other organizations. It is import to note that only the minority of examples refers to RS activations for conducting disaster risk analyses in fragile contexts. However, this table is a unique comparison of experts' experiences with RS activations, which is unknown in the literature so far. Moreover, it is essential to disseminate these cases to advance organizational learning.

What these examples in Figure 9 have in common is that they shed light on different potentials and pitfalls of RS in fragile contexts. Figure 9 yields three key lessons: First, the picture is *heterogeneous* with seven positive, four critical and five negative examples. Second, on the positive side, experts brought several (internal) mechanisms and policies but only three country cases as good practice into play, namely Cox Bazar, Bangladesh (see pp. 10 & 20 in this work and NASA 2019), Western Balkans and the Mekong Delta in Vietnam. However, only the former case in Bangladesh is considered a RS application in regarding the disaster–fragility nexus due to context of forced displacement of Rohingya refugees. Third, on the more critical yellow and red side, experts mentioned several country cases in Syria, Sudan, Yemen, South Sudan, Ethiopia and Haiti but less mechanisms and policies. Lastly, each of the 15 examples reveals a particular lesson learned which is explained in the discussion.

Figure 9: Experts' Examples for RS Applications in Fragile Contexts

Legend: ◯ = Good practice | ◯ = Ambivalent/Critical | ◯ = Negative example | I = Interview number, a = anonymized[11]

I	Policy/ Country	Experts description of positive / negative elements	Lesson Learned
11	Standards and certification	• DLR utilizes standardized ISO-certified processes for RS activations and image processing to implement quality control	Benefit of internal standards, quality control
11	Humanitarian Technology Initiative	• DLR organizing Humanitarian Technology Initiative and NGO partnerships, cooperating with Human Rights Watch, Doctors Without Borders, SOS Kinderdoerfer	Benefit of cooperation with nonstate actors
10	Famine Early Warning System Network	• Maxar supports monitoring famine prone and inaccessible areas in 38 countries, use of crowdsourcing, machine learning, AI for ground validation and accuracy assessments	Benefit of cooperation with nonstate actors, method diversity for ground validation
9	Pilot projects	• GIZ upcoming pilot projects on joint climate and disaster risk analyses in fragile contexts, DRM advise for partner government of a fragile country in South-Sahara Africa	Benefit of intra-organizational cooperation, pilot projects and policy advice
8	Bangladesh, Cox Bazar	• NASA implementing integrated approach to analyze landslide and flood risks for Rohingya settlements; cooperating with IOM, UNDP, UNHCR, NGO's on the ground for over two years, field trip and downscaling of products according to end-user needs and capacities	Benefit of integrated approach, intersectoral cooperation, localization, downscaling, long-term
5	Digital Principles	• Multilateral IO's and NGO's Principles for Digital Development[12], guidance for applications of digital technologies to development programs	Benefit of guidance for digital technology applications
2 3 5 8 11	Copernicus CEMS, Western Balkans and Vietnam	• GIZ/BBK applications of CEMS 'risk and recovery' mode for prevention purposes in case of flood risk management in Western Balkans and ground subsidence in Mekong delta in Vietnam, EU funded, large-scale and long-term service	Benefit of institutionalization, budget, long-term planning, prevention and open data

[11] No sorting order of examples within colored areas; critical and negative examples were anonymized by the author to protect the source of information.
[12] Principles for Digital Development: https://digitalprinciples.org/ .

	Copernicus CEMS	• Many intermediate steps and stakeholders involved, limited flexibility • Partners side: data heterogeneity and non-acceptance of CEMS data	Costs of intermediate steps, administration; lack of compatibility and partner acceptance
a	Syria, Aleppo	• Harvard Humanitarian Initiative[13] decision against sharing satellite imagery with White Helmets who requested escape route for 150 vulnerable people within 48 hours; ethical and political challenges	Consequences of image publication to avoid harm, UNI[14], ethics and politicization of RS data
a	Sudan	• Challenging project implementation: missing buy-in from national authorities and political restrictions in post-conflict, displacement situations	Consequences of (missing) governance, politicization
a	Yemen	• Decision against RS due to large uncertainty and inaccuracy w/o ground validation, RS not useful for pressing needs in project context	Consequences of large uncertainty w/o validation
a	Cyclone Idai	• Multiple humanitarian emergencies at the same time, limited capacity of UNOSAT, UN doing prioritization, had to leave emergencies behind	Triage of services, emergencies left behind
a	South Sudan	• Imagery misuse by bad actors due to recognition of sensitive data, leading to kidnapping of Chinese workers and destruction of huge infrastructure project; 'too quick' release of satellite imagery, things out of control	Risk of harm and UNI due to misuse of sensitive data by local (conflict) parties
a	Sudan	• Night light assessments: not detecting community but industrial lights due to dynamic, conflict-related displacement and industrial occupation	Risk of misinterpretation w/o validation, dynamic
a	Ethiopia	• Vegetation index: satellite imagery yields index increase, but real cause was growing presence of invasive species, leading to deterioration	Risk of misinterpretation, deterioration w/o validation
a	Haiti	• (Physical) vulnerability: rooftops of some multilevel buildings seemed intact after the 2011 earthquake, but the buildings had totally collapsed	Risk of misinterpretation w/o validation due to 'hidden' vulnerability

[13]The Washington Post (2017): https://www.washingtonpost.com/news/monkey-cage/wp/2017/01/09/we-tried-to-save-150-people-in-aleppo-from-5000-miles-away/.
[14] Unintended negative impacts (UNI), see Fn. 9.

VIII. KEY FINDINGS

This section presents key findings from the empirical analysis and answers the research question: *Does remote sensing improve disaster risk analyses in fragile contexts?* Figure 10 summarizes all (sub-) themes that emerged from the expert interviews.

Figure 10: Summary of (Sub-)Themes from the Empirical Analysis

(Sub-) Theme Specification		
Question	**Positive**	**Critical/ Negative**
Problem of disaster risk analyses in fragile contexts	-	*Access*: field access, access to information and access to functioning structures and institutions
	-	*Governance*: lack of governance and public administration interest
	-	*Data availability and quality*: data scarcity, low data quality
	-	*Risk equation*: complexity, imbalance between components, vulnerability
Role of RS as solution	*Functionality*: facilitate access to information, improve scope and time	-
	Complementation: validation of statistical and in-situ data	-
	Data availability and quality: data acquisition, objectivity, reliability	-
	Risk equation and DRM-Cycle: for natural hazards and exposure	-
Limitations of RS	-	*Do-No-Harm*: potential for harm and unintended negative impacts (UNI)
	-	*Data availability and quality:* lack of complementation, validation, biases
	-	*Governance:* lack of capacities, expertise, interest and awareness
	-	*Risk equation and the DRM-Cycle*: vulnerability, use of proxy indicators
Supporting and Inhibiting factors	*Basic requirements and integration*: fulfil minimum institutional requirements, interest and safe access to cooperate, validate and build capacities	*Complexity and dependencies*: absence of support factors, RS complexity and intermediate steps, local politicization, corruption, no structure and staff
Trade-offs & decision-making-procedures	*Internal procedures:* interdisciplinary expertise, compliance with quality standards, four-eye principle	*Silo-thinking and transaction costs*: no transferability of standards, many intermediate steps and stakeholders, transaction costs of cooperation, public-private

	External procedures: political regulation, intersectoral cooperation and localization for validation	divide, staff resistance, no data sharing and politicization
Examples – lessons learned	Potentials: internal standards, contextualization, local to multilateral cooperation, different validation methods, integrated and intersectoral approaches, institutionalization and long-term planning	Pitfalls: lack of governance, interest and capacities, politicization; institutional and procedural complexity, data biases, misinterpretation, uncertainty; triage, unintended negative impacts and harm

Source: own elaboration. Themes and sub-themes taken from the empirical analysis.

Since this work roots in evidence-based policymaking, trustworthy arguments have to exist to allow for the effectiveness prediction for the positive causal role of RS in fragile contexts. Evidence from the empirical part suggests that RS unleashes its full potential under certain *conditions* and *support factors* that are represented by positive (sub-)themes in the green area in Figure 10; the most important ones being *access*, *complementation and validation*, *data availability and quality, basic institutional requirements*, *governance*, *compliance with internal and external procedures* including *Do-No-Harm* as well as *cooperation*. If these conditions are met and the support factors are present, it is likely that RS — as complementary source of information — advances understanding of disaster risks, sheds light on the risk equation and supports subsequent DRM measures. These conditions and support factors, however, primarily apply to *non*-fragile contexts.

Fragile contexts, in contrast, are characterized by the absence or deterioration of conditions and support factors *and* by complex sets of additional negative and inhibiting elements — see red area in Figure 10. For example, if RS is the only source of information, data may not be *validated* and the risk equation lacks understanding of *vulnerability*. Even if RS data is validated, *unintended negative impacts* can result from *image abuse*, *biases, errors, misinterpretation, politicization*, *uncertainty* and other types of *complexity and dependencies* in fragile contexts nonetheless. Finally, *silo-thinking and transaction costs* may prevail, inhibiting cooperation. Thus, it is essential to recognize different sources of flawed understanding, decision-making and potential for *harm*[15]. Coming back to the three pillars of the effectiveness prediction (see Figure 1), the findings imply:

[15] Furthermore this includes: wrong data in right hands leading to wrong decisions; right data in wrong hands; right data in right hands without capacities; right data that might be wrong or go into wrong hands in the future.

1) RS plays a positive causal role, improving disaster risk analyses, in *non*-fragile contexts, the support factors and conditions are in place[16].
2) The support factors necessary for RS to play a positive causal role for disaster risk analyses in fragile contexts are often *not* in place.
3) The analysis has shown that RS does *not* play the same causal role in fragile contexts as it does in non-fragile contexts. Conclusive evidence yields that the causal role of RS in fragile contexts cannot be defined due to several dependencies and dynamic circumstances.

Taken together — as highlighted by Figure 1, 9 and 10 — the second and the third pillar do *not* allow for the *effectiveness prediction* that remote sensing will improve disaster risk analyses in fragile contexts as well (Cartwright/Hardie 2012: 51–55). Both the process and the outcome of RS for disaster risk analyses in fragile contexts depend on several conditions and unpredictable contextual factors – in short: the risks of remote sensing for disaster risk analyses in fragile contexts.

> *In light of these key findings, it is not possible to make a robust effectiveness prediction and the null hypotheses (H_0) cannot be falsified. Consequently, — under certain circumstances highlighted above — it holds true that remote sensing does not improve disaster risk analyses in fragile contexts and the hypothesis (H_1) is rejected.*

To refer back to the theoretical part, this result contradicts promises regarding the application of RS 'without risk' or to 'narrow down uncertainty in disaster risk analysis' (ESA 2015: 6–11). Every fragile context includes 'dynamic factors and root causes' and 'unique sets of multiple interacting risks' (UNDRR 2019: 65–68). This thesis finds that RS has ambiguous feedback effects. Moreover, in some contexts, RS entails and creates its own unique set of risks and uncertainty. For instance, as fragility increases (intersecting) vulnerabilities to hazards, the disaster risk analysis with RS, e.g. using proxy indicators, can backfire due to several circumstances listed above, even increasing vulnerability and causing harm — see yellow and red area in Figure 9. Regarding the disaster–fragility nexus it was highlighted that disasters are politically sensitive and not conflict-neutral (ODI 2019: 17–18). The present analysis finds that both insights apply for the RS–fragility nexus as well. In some cases, RS has proven to be politically sensitive and not conflict-neutral. Lastly, in

[16] The assumption and dichotomy here is a simplification, because fragile contexts are the focus of this work. Alternatively, policymakers may 'require significantly less time and resources to introduce necessary support factors in non-fragile contexts'.

context of the Sendai Framework Priorities for Action, this work contributed to recognizing the potentials and pitfalls of RS, shedding light on the 'understanding of risks'. Thus, risk analyses which include the 'interlinkages of multiple risks and actors across systems' (UNDRR 2019: 65–68) need to incorporate risks of own interventions with digital technologies as well.

IX. DISCUSSION

This work has revealed two paradoxes: first, although each of the three components of the research question — RS, climate and disaster risks and fragile contexts — has become more prominent in the last decade, their combination is only recently emerging in the literature. Second, the process and the consequence of using RS for risk analyses yields ambiguous feedback effects and can be a risky endeavor in itself. A particular focus has been the empirical analysis with eleven expert interviews, including the humanitarian, development and space community. Interestingly, experts have put 15 examples forward — displayed in Figure 9 — that yield particular lessons learned. The green shaded area, including seven examples, illustrates the benefits of *internal standards, multi-stakeholder cooperation, diversity of validation methods, integrated and intersectoral approaches, institutionalization and long-term planning*.

In contrast, the yellow and red shaded areas in Figure 9 highlight drawbacks due to *institutional and procedural complexity, lack of (partner) governance, acceptance, expertise and capacities, biases, politicization, triage, misinterpretation, uncertainty, unintended negative impacts* and *harm*. Overall, the diversity of perspectives has enriched the research process and shown the great potential of multi-stakeholder cooperation. Furthermore, most publications and interviewed experts already exhibit an interdisciplinary understanding of potentials and pitfalls of RS. However, as Figure 9 shows, positive examples are limited to policies, mechanism and pilots, whereas long-term intersectoral cooperation is rare.

Finally, Figure 11 illustrates five recurrent discussion lines, which give enough cause for intra- and inter-organizational learning and action, subsequently described in the policy recommendations.

Figure 11: Five Discussion Lines from the Empirical Analysis

Argument		Counterargument
Stand-alone tool, top-down, quick & dirty assessments	⟺	Need complementation, validation, contextualization, localization
No-regret tool, objective, accurate, reliable uncertainty o.k.	⟺	Do-No-Harm, conflict sensitivity, biases, errors, large uncertainty
Covers whole risk equation, use of proxy indicators o.k.	⟺	Does not cover vulnerability, no use of proxy indicators
Short term disaster response, particular use cases, short lifespan	⟺	Long-term prevention, preparedness, service interoperability and continuity
Silo-thinking, transaction costs, project-based progress	⟺	Stakeholder integration, cooperation, institutionalized progress

Source: own elaboration based on literature review, desk study and expert interviews.

However, this analysis also entails biases and key perspectives that were not included in the research process due to limited research capacities and the outbreak of the COVID-19 pandemic, among others. Furthermore, it is important to highlight the selection bias of interviewees, namely that experts have been contacted for example due to their acknowledged expertise on DRM and/or RS and/or fragile contexts. Other perspectives include e.g. civil society organizations and NGO's, different end-users as well as private sector companies and development banks. Nevertheless, this work contributes to ground the potentials and pitfalls of RS applications, recognizing the limitations and feedback effects of digital technologies in fragile systems and acknowledging (potential) uncertainty, bias, misinterpretation, error and ultimately, unintended negative impacts and harm. The results emphasize the particular responsibility of organizations operating in fragile contexts to reflect on their sense of security to understand the impact of digital technologies in the particular fragile contexts. Finally, these findings enrich open debates on the application of other digital (RS) tools such as drones, mobile data and machine learning.

X. POLICY RECOMMENDATIONS

The following policy recommendations originate from discussions with the interviewed experts and merge with own insights drawn from the analysis. The policy recommendations are divided into a universal section for all stakeholders and three sub-sections for humanitarian and development experts, for providers and aerospace agencies and national decision-makers.

For All Stakeholders:

Foster intra- and interorganizational learning and action. The overall aim is to ensure a process of pooling and exchanging intersectoral and interdisciplinary knowledge to overcome silo-thinking and bolster more coherent, better integrated approaches on the nexus of remote sensing, risk-informed development and fragile contexts e.g. in preparation for the next Global Platform for DRR.

- *Strengthen* **in-house** capacities:
  - *Pool* in-house technical and scientific expertise on RS as well as the use of digital tools in fragile contexts
  - *Train* staff on analytical capacities for RS data, considering low-threshold entries and advanced trainings for different disciplinary backgrounds
  - *Advance* intra-organizational learning and transparency regarding good practices and challenges at the intersection of RS, risk-informed development and fragile contexts with a special focus on Do-No-Harm and potential unintended negative impacts such as due to politicization and misuse of data
  - *Assess* transferability of internal standards and guidelines for RS in highly dynamic environments, considering the development of new mechanisms for fragile contexts and the acquisition of updated in-depth knowledge on a case-by-case bases
  - *Monitor* and *evaluate* institutional and project-based experiences with RS
  - *Prioritize* validation on the ground, compatibility of data and development of better integrated, contextualized, localized and cooperative approaches to get/analyze data
  - *Scale-up* internal capacities for networking, cooperation and partnership management, considering an interdisciplinary focal point in your structure
  - *Raise* awareness for data protection and data sharing among (sub-)entities
- *Cooperate* with **peer organizations**: strengthen open dialogue on how to improve joint understanding, in-house-capacities, services, communication and process simplification

- *Cooperate* with **different stakeholders**:
  - *Advance* the global community of practice, coordinated under UN mandate (including UNSPIDER, JEU, UNDRR) to enable multi-stakeholder cooperation between providers, aerospace agencies, humanitarians, international development, finance, academia, NGO's, national policymakers and UN-organizations on the use of RS in fragile systems to enable risk-informed development
  - *Improve* access to services and synergistic use of different sources of information for complementation, calibration and validation
  - *Consider* staff exchange and lower transaction costs for cooperation, raise awareness for potentials and pitfalls of RS data

<u>For (End-) Users in Humanitarian Aid and International Development</u>

- *Acquire* the best possible in-situ knowledge, cooperate and communicate with people working in-situ to ensure accuracy, calibration, complementation and validation of RS data
- *Foster* exchange between humanitarian & development communities, disseminate experiences with Do-No-Harm and conflict-sensitive approaches in fragile contexts, consider a conflict analysis to understand dynamic contexts and unintended negative impacts
- *Enhance* Transitional Aid to strengthen basic requirements, interlinkages of DRM-phases and local capacity building in partner organizations to generate and process RS data
- *Bolster* the GRAF (UNDRR) process to seek a comprehensive understanding of systemic vulnerabilities *of* the system (e.g. fragile context) rather than assessing the vulnerability of a single element *in* the system and interlinkages of multiple risks and actors *across* systems
- *Shed light* on the difficult and less visible parts in the risk equation and the DRM cycle: *Advocate* for more prevention and preparedness in development projects and partner institutions, including long term planning and resilience-dividend for risk-informed development, but be careful with using proxy indicators
- *Elaborate* concrete cost-benefit analyses and financial figures to show national policymakers the resilience-dividend — the return of investment — and the unique benefits and limitations of RS in the particular context, elaborate guidelines with national decision-makers for the use of RS data in fragile contexts

For Providers and Aerospace Agencies

- *Enhance* transparency regarding potentials: data availability, objectivity, reliability, accuracy, high-resolution as well as pitfalls: in-built subjectivity, biases, inherent risks and uncertainty, type one and type two errors, consider advanced trainings on data theory and the potential for unintended negative impacts and harm in fragile contexts
- *Enable* more complementary, comprehensive analyses of entire (fragile) systems: enhance satellite and data interoperability and integration of data products, seek combinations of different methods to calibrate and validate data and facilitate ground control
- *Increase* foresight in the development of multiple-use, long-term products and integrated methods for systematic analysis of climate and disaster risks in fragile contexts
- *Scale-up* on robust and reliable method development which apply for (less profitable) low- and mid-resolution commercial imagery, open data and open source for larger areas
- *Simplify* analytical process and communication according to the user's capacities, share technical expert knowledge and support physical and human capacity building

For national decision-makers

- *Fund and advance* the global community of practice under UN mandate (including UNSPIDER, JEU, UNDRR)
- *Fill* risk-informed development in fragile contexts with live:
    - *Increase* contributions to multilateral and bilateral organizations' portfolios on RS for (climate/disaster) risk-informed development in fragile contexts
    - *Invest* in global public goods and long-term planning: advocate for national buy-in and long-term planning such as the resilience-dividend, conduct cost-benefit analyses for finance ministries to show the return of investment
    - *Recognize* the value and the usefulness of reliable information on risks and develop policy guidelines for dealing with RS data in fragile contexts
- *Demand* service interoperability for comprehensive system analyses including multiple-use and long-term products assessing elements of vulnerability and fragility more coherently

- *Seek* low-threshold entries such as national census before RS, assign proper value to the cost of reliable data, develop suitable legislation to process, analyze and share data among (sub-)entities, ensure data protection and find a compromise for use of mid-resolution data and external analytical support
- *Continue* to support the Copernicus (CEMS) 'risk and recovery' mode, considering it as role model for global institutionalization processes, avoiding over-structuring
- *Finance* research and development at the intersection of RS/ digital technologies, risk-informed development and fragile contexts; consider an interdisciplinary student exchange and doctorate program

XI. CONCLUSION

This work generated, tested and disseminated knowledge concerning the question to what extent satellite remote sensing (RS) improves disaster risk analyses in fragile contexts. This work triangulated primary and secondary sources with eleven expert interviews. RS is an omnipresent option for all regions, hazard types and stages of the DRM-Cycle. Regarding potentials, RS entails the ability to assess large areas in less time, save costs, get high-resolution imagery and, in case of disaster response, it is often the first source of information. The analysis yields that process and outcome of RS activations are conditional and require several support factors to unleash its full potential. Key findings suggest that these conditions mainly apply to non-fragile contexts — namely *access, complementation and validation, data availability and quality, basic institutional requirements, governance, compliance with internal and external procedures* including *Do-No-Harm* as well as *cooperation*.

Fragile contexts, however, differ fundamentally from non-fragile contexts. They are characterized by the absence and deterioration of conditions and support factors as well as by different sets of additional negative and inhibiting elements. Regarding the pitfalls, if RS is the only source of information, data may not be validated and the risk equation and subsequent DRM measures lack understanding of vulnerability. Even if RS data is validated, *unintended negative impacts* can result from *image abuse*, *biases, errors, misinterpretation*, *politicization*, *uncertainty* and other types of *complexity and dependencies* in fragile contexts nonetheless. Finally, *silo-thinking and transaction* *costs* may inhibit *cooperation*. Thus, it is essential to recognize different sources of flawed understanding, decision-making and potential for *harm*[17]. This work has shown that RS activations in fragile contexts must be accompanied by an evidence-based understanding of all factors inherent to the fragile system and the system of origin. This requires the generation of updated in-depth knowledge on a case-by-case basis and questions the transferability of existing standards and processes.

It results that the use of RS for disaster risk analyses in fragile contexts is a risky endeavor in itself and entails potential for ambiguous feedback effects. In some cases, RS has proven to be politically sensitive and not conflict-neutral. Since the process of disaster risk analyses with RS entails the potential for unintended negative impacts, the outcome may not be sustainable. The collected evidence does not allow for a robust effectiveness prediction vis-à-vis the positive causal role of RS in fragile contexts. Thus, the null hypothesis cannot be rejected and it holds true that — under certain circumstances — remote sensing does not improve disaster risk analyses in fragile contexts. These findings matter to understand potentials and pitfalls of digital technologies in fragile systems. Lastly, policy recommendations encourage intra- and inter-organizational learning and action, including open debates, project evaluation, resource pooling, advancing a community of practice and multi-stakeholder cooperation to pave a safer way toward risk-informed development.

[17] Including wrong data in right hands leading to wrong decisions; right data in wrong hands; right data in right hands w/o (analytical) capacities; right data that is wrong or goes into wrong hands in the future, among others.

ANNEX

Annex 1: Questionnaire for Expert Interviews

#	Basic Questions and in-depth possibilities
0	Presentation: May you introduce yourself and your area of work?
1	Do you see a problem with conducting risk analysis in fragile contexts? A) Which and why? B) What are the root causes of this problem?
2	Which role does remote sensing play as part of the solution for disaster risk analyses in fragile contexts? A) What is special about your approach? B) On which part of the risk equation / DRM-Cycle do you focus? C) How does it distinguish you from other approaches (e.g. CEMS)? D) What are the alternatives
3	What are the limitations of employing remote sensing in fragile contexts? A) Which factors inhibit and support the use of remote sensing in practice? B) What if validation & localization, in-situ/community perspective not possible? C) Do you identify unintended negative consequences? Which and Why?
4	How do governance trade-offs and decision-making procedures look like, which speak for and against employing remote sensing? A) Who decides and involved in the decision-making process for an activation? B) What does it cost/save? Does the ‘Resilience-Dividend’ play a role? C) How do you collaborate with partner governments/ other institutions?
5	Do you have examples of good practice - challenges? Why?
6	Discussion on Policy Recommendations: what needs to improve for the use of RS in fragile contexts?

Source: own elaboration.

Annex 2: DRM Terminology

Capacity:

The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience. Capacity may include infrastructure, institutions, human knowledge and skills and collective attributes such as social relationships, leadership and management.

> **Coping capacity** is the ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks.

Disaster Risk Assessment:

A qualitative or quantitative approach to determine the nature and extent of disaster risk by analyzing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend. Disaster risk assessments include: the identification of hazards; a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability, including the physical, social, health, environmental and economic dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities with respect to likely risk scenarios.

Disaster Risk Governance:

The system of institutions, mechanisms, policy and legal frameworks and other arrangements to guide, coordinate and oversee disaster risk reduction and related areas of policy. Good governance needs to be transparent, inclusive, collective and efficient to reduce existing disaster risks and avoid creating new ones.

Disaster Risk Reduction (DRR):

Disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development. Disaster risk reduction is the policy objective of disaster risk management and its goals and objectives are defined in disaster risk reduction strategies and plans.

Disaster Risk Management (DRM):

Disaster risk management is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses. Disaster risk management actions can be distinguished between prospective disaster risk management, corrective disaster risk management and compensatory disaster risk management, also called residual risk management.

Disaster risk management plans set out the goals and specific objectives for reducing disaster risks together with related actions to accomplish these objectives. They should be guided by the Sendai Framework for Disaster Risk Reduction 2015-2030 and considered and coordinated within relevant development plans, resource allocations and programme activities. National-level plans need to be specific to each level of administrative responsibility and adapted to the different social and geographical circumstances that are present. The time frame and responsibilities for implementation and the sources of funding should be specified in the plan. Linkages to sustainable development and climate change adaptation plans should be made where possible.
Elements at risk (EaR): Population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area, also referred to as "assets." The amount of EaR can be quantified either in numbers (of buildings, people, etc.), area, in monetary value (replacement costs, market costs, etc.), or perception (importance of elements at risk EaR).
Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. Annotation: Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.
Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be natural, anthropogenic or socionatural in origin. Natural hazards are predominantly associated with natural processes and phenomena. Anthropogenic hazards, or human-induced hazards, are induced entirely or predominantly by human activities and choices. This term does not include the occurrence or risk of armed conflicts and other situations of social instability or tension, which are subject to international humanitarian law and national legislation. Several hazards are socionatural, in that they are associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change. Hazards may be single, sequential or combined in their origin and effects. Each hazard is characterized by its location, intensity or magnitude, frequency and probability. Biological hazards are also defined by their infectiousness or toxicity, or other characteristics of the pathogen such as dose-response, incubation period, case fatality rate and estimation of the pathogen for transmission. **Multi-hazard** means (1) the selection of multiple major hazards that the country faces and (2) the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time and taking into account the potential interrelated effects. Hazards include (as mentioned in the Sendai Framework for Disaster Risk Reduction

2015-2030 and listed in alphabetical order) biological, environmental, geological, hydrometeorological and technological processes and phenomena.

Preparedness:

The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters. Preparedness action is carried out within the context of disaster risk management and aims to build the capacities needed to efficiently manage all types of emergencies and achieve orderly transitions from response to sustained recovery. Preparedness is based on a sound analysis of disaster risks and good linkages with early warning systems and includes such activities as contingency planning, the stockpiling of equipment and supplies, the development of arrangements for coordination, evacuation and public information and associated training and field exercises. These must be supported by formal institutional, legal and budgetary capacities. The related term "readiness" describes the ability to quickly and appropriately respond when required.

Prevention:

Activities and measures to avoid existing and new disaster risks. Prevention (i.e., disaster prevention) expresses the concept and intention to completely avoid potential adverse impacts of hazardous events. While certain disaster risks cannot be eliminated, prevention aims at reducing vulnerability and exposure in such contexts where, as a result, the risk of disaster is removed. Examples include dams or embankments that eliminate flood risks, land-use regulations that do not permit any settlement in high-risk zones, seismic engineering designs that ensure the survival and function of a critical building in any likely earthquake and immunization against vaccine-preventable diseases. Prevention measures can also be taken during or after a hazardous event or disaster to prevent secondary hazards or their consequences, such as measures to prevent the contamination of water.

Recovery:

The restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and "build back better", to avoid or reduce future disaster risk**.**

Remote Sensing (Thompson 2019: 490):

The technique of obtaining information about objects through the analysis of data collected by instruments that are not in physical contact with the object of investigation. In a climate context, remote sensing is commonly performed from satellites or aircraft.

Resilience: 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.
Response: Actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected. Disaster response is predominantly focused on immediate and short-term needs and is sometimes called disaster relief. Effective, efficient and timely response relies on disaster risk-informed preparedness measures, including the development of the response capacities of individuals, communities, organizations, countries and the international community. The institutional elements of response often include the provision of emergency services and public assistance by public and private sectors and community sectors, as well as community and volunteer participation. “Emergency services” are a critical set of specialized agencies that have specific responsibilities in serving and protecting people and property in emergency and disaster situations. They include civil protection authorities and police and fire services, among many others. The division between the response stage and the subsequent recovery stage is not clear-cut. Some response actions, such as the supply of temporary housing and water supplies, may extend well into the recovery stage.
Risk (Thompson 2019: 491): The likelihood of harmful consequences arising from the interaction of hazards, communities and the environment; the chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood; a measure of harm, taking into account the consequences of an event and its likelihood. The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted, or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions. Conventionally, risk is expressed by the notation: *Risk = Hazard x Exposure x (Vulnerability/ Coping Capacity)* The term risk refers to the expected losses from a particular hazard to a specified element at risk in a particular future time period. Loss may be estimated in terms of human lives, buildings destroyed, or in financial terms. The combination of the likelihood and the consequence of a specified hazard being realized; refers to the vulnerability, proximity, or exposure to hazards, which affects the likelihood of adverse impact. An abstract concept closely related to uncertainty with different definitions in different disciplines. In disaster risk reduction, risk is considered a function of hazard, exposure, vulnerability and values of elements at risk. Risks are mental “constructions;” they are not real phenomena but originate in the human mind. Risks are abstract and cannot be managed; only the outcome can be managed. Risks may have impact far beyond the initial incident location due to the interwoven network of the nation’s critical infrastructure. Risks have the potential of being exacerbated by changes in environmental conditions and failing infrastructure.

Vulnerability:
The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. For positive factors which increase the ability of people to cope with hazards, see also the definitions of “Capacity” and “Coping capacity”. Since damage can be inflicted on physical EaR as well as systems and processes, different types of vulnerability exist. Typically considered in DRM are physical, social, environmental and economic. However, the vulnerability of other systems also, such as political or institutional, can be considered. Vulnerability should always be assessed as a function of a given hazard type and magnitude.

If not stated otherwise, the source for each term is (UNDRR 2020b).

REFERENCES:

Aka, F. T., Buh, G. W., Fantong, W. Y., Issa, Zouh, I. T., Djomou, S. L. B., Ghogomu, R. T., Gibson, T., Marmol del, M.-A., Sigha, L. N., Ohba, T., Kusakabe, M., Yoshida, Y., Tanyileke, G., Nnange, J. M. & Hell, J. V. (2017). Disaster prevention, disaster preparedness and local community resilience within the context of disaster risk management in Cameroon. *Natural Hazards*, *86*(1), 57–88. https://doi.org/10.1007/s11069-016-2674-5

Alizadeh, M., Ngah, I., Hashim, M., Pradhan, B., Pour, A. (2018). A Hybrid Analytic Network Process and Artificial Neural Network (ANP-ANN) Model for Urban Earthquake Vulnerability Assessment. *Remote Sensing*, *10*(6), 975. https://doi.org/10.3390/rs10060975

Anderson, M. B. (1999). *Do no harm: How aid can support peace--or war*. Lynne Rienner Publishers. Boulder, Colorado.

Asmamaw, L. & Mohammed, A. (2019). Identification of soil erosion hotspot areas for sustainable land management in the Gerado catchment, North-eastern Ethiopia. *Remote Sensing Applications: Society and Environment*, *13*, 306–317. https://doi.org/10.1016/j.rsase.2018.11.010

Baas, S. & Food and Agriculture Organization of the United Nations (Eds.). (2008). *Disaster risk management systems analysis: A guide book*. Food and Agriculture Organization of the United Nations. Rome, Italy.

Bertelsmann Stiftung. (2020). *BTI 2020 | Ergebnisüberblick—Transformationsindex der Bertelsmann Stiftung. Machtmissbrauch und Vetternwirtschaft untergraben Demokratie und Marktwirtschaft*. https://bti-project.org/de/meta/downloads.html

BMZ (2015). *Disaster Risk Management. Approach and Contributions of German Development Cooperation*. BMZ Division for Public Relations, Digital Communications. https://www.bmz.de/en/publications/type_of_publication/information_flyer/information_brochures/Materialie245a_disaster_risk_managment.pdf

BMZ (2019). *Comprehensive Risk Management. The Approach of German Development Cooperation for Dealing with Disaster and Climate Risks.* www.bmz.de/en/publications/topics/climate/Materilie400_risk_management.pdf

Boateng, I. (2012). GIS assessment of coastal vulnerability to climate change and coastal adaption planning in Vietnam. *Journal of Coastal Conservation*, *16*(1), 25–36. https://doi.org/10.1007/s11852-011-0165-0

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Capes, R. & Teeuw, R. (2017). On safe ground? Analysis of European urban geohazards using satellite radar interferometry. *International Journal of Applied Earth Observation and Geoinformation*, *58*, 74–85. https://doi.org/10.1016/j.jag.2017.01.010

Cartwright, N./ Hardie, J. (2012). *Evidence-based policy: A practical guide to doing it better*. Oxford, United Kingdom. Oxford Univ. Press.

Chaudhri, S., Cordes, K., Miller, N. (2019). Humanitarian health programming and monitoring in inaccessible conflict settings: A literature review. *Journal of International Humanitarian Action*, *4*(1), 9. https://doi.org/10.1186/s41018-019-0055-x

Christoplos, I. (2010). *The multiplicity of climate and rural risk*. Danish Institute for International Studies.

Cilliers, D. P. (2019). Considering flood risk in spatial development planning: A land use conflict analysis approach. *Jàmbá: Journal of Disaster Risk Studies*, *11*(1). http://dx.doi.org.proxy1.library.jhu.edu/10.4102/jamba.v11i1.537

CRED/ UNDRR. (2018). *Economic Losses, Poverty & Disasters 1998–2017.* https://www.undrr.org/publication/economic-losses-poverty-disasters-1998-2017

Dandapat, K. & Panda, G. (2018). A geographic information system-based approach of flood hazards modelling, Paschim Medinipur district, West Bengal, India. *Jàmbá: Journal of Disaster Risk Studies*, *10*(1). https://repository.nwu.ac.za/handle/10394/28554

Dang, A. & Kumar, L. (2017). Application of remote sensing and GIS-based hydrological modelling for flood risk analysis: A case study of District 8, Ho Chi Minh city, Vietnam. *Geomatics, Natural Hazards and Risk*, *8*(2), 1792–1811. https://doi.org/10.1080/19475705.2017.1388853

Davidson, R. (2013). Application of remote sensing in support of regional disaster risk modeling: Short Communication for Special Issue of Natural Hazards entitled "Remote sensing contributing to mapping earthquake vulnerability and effects." *Natural Hazards*, *68*(1), 223–224. https://doi.org/10.1007/s11069-013-0587-0

Deafalla, T., Csaplovics, E., El-Abbas, M. (2014). *The application of remote sensing for climate change adaptation in Sahel region*. *SPIE Remote Sensing*. Amsterdam, Netherlands. https://doi.org/10.1117/12.2067460

Deutsche Gesellschaft fuer Internationale Zusammenarbeit GmbH (giz) (2020). *The Safeguards and Gender Management System*. https://www.giz.de/en/aboutgiz/76608.html

Deutsche Gesellschaft fuer Internationale Zusammenarbeit GmbH (giz) (2014). *The Vulnerability Sourcebook. Concept and guidelines for standardised vulnerability assessments.* Metzgerdruck, Obrigheim.

Diack, M., Loum, M., Diop, C. T., Holloway, A. (2017). Quantitative risk analysis using vulnerability indicators to assess food insecurity in the Niayes agricultural region of West Senegal. *Jàmbá: Journal of Disaster Risk Studies*, *9*(1). https://doi.org/10.4102/jamba.v9i1.379

Dube, E., Mtapuri, O., Matunhu, J. (2018). Managing flood disasters on the built environment in the rural communities of Zimbabwe: Lessons learnt. *Jàmbá: Journal of Disaster Risk Studies*, *10*(1), 11. https://doi.org/10.4102/jamba.v10i1.542

Eklund, L. & Thompson, D. (2017). Differences in resource management affects drought vulnerability across the borders between Iraq, Syria and Turkey. *Ecology and Society*, *22*(4). https://doi.org/10.5751/ES-09179-220409

Elia, A., Balbo, S., Boccardo, P. (2018). A quality comparison between professional and crowdsourced data in emergency mapping for potential cooperation of the services. *European Journal of Remote Sensing*, *51*(1), 572–586. https://doi.org/10.1080/22797254.2018.1460567

ESA (2015). The Committee on Earth Observation Satellites (CEOS) & European Space Agency (ESA) Earth Observation Handbook for WCDRR. Satellite Earth Observations in support of Disaster Risk Reduction. *Special 2015 WCDRR Edition*. Paris, France. http://www.eohandbook.com/wcdrr/

European Commission. (2020). *Copernicus Emergency Management Service*. https://emergency.copernicus.eu/

Fekete, A. (2019). Social Vulnerability (Re-)Assessment in Context to Natural Hazards: Review of the Usefulness of the Spatial Indicator Approach and Investigations of Validation Demands. *International Journal of Disaster Risk Science*, *10*(2), 220–232. https://doi.org/10.1007/s13753-019-0213-1

Fekete, A. et al. (2015). Critical Data Source; Tool or Even Infrastructure? Challenges of Geographic Information Systems and Remote Sensing for Disaster Risk Governance. *ISPRS International Journal of Geo-Information*, *4*(4), 1848–1869. https://doi.org/10.3390/ijgi4041848

Fekete, A., Tzavella, K., Baumhauer, R. (2017). Spatial exposure aspects contributing to vulnerability and resilience assessments of urban critical infrastructure in a flood and blackout context. *Natural Hazards*, *86*(S1), 151–176. https://doi.org/10.1007/s11069-016-2720-3

Fenta, M., Jordaan, A., Melka, Y. (2019). Vulnerability of Southern Afar pastoralists to climate variability and change, Ethiopia. *Jàmbá: Journal of Disaster Risk Studies*, *11*(1). https://doi.org/10.4102/jamba.v11i1.575

Franci, F., et al. (2016). Satellite remote sensing and GIS-based multi-criteria analysis for flood hazard mapping. *Natural Hazards*, *83*(S1), 31–51. https://doi.org/10.1007/s11069-016-2504-9

Franci, F., Mandanici, E., & Bitelli, G. (2015). Remote sensing analysis for flood risk management in urban sprawl contexts. *Geomatics, Natural Hazards and Risk*, *6*(5–7), 583–599. https://doi.org/10.1080/19475705.2014.913695

Gall, M., Nguyen, K. H. & Cutter, S. L. (2015). Integrated research on disaster risk: Is it really integrated? *International Journal of Disaster Risk Reduction*, *12*, 255–267. https://doi.org/10.1016/j.ijdrr.2015.01.010

Geiß, C. et al. (2017). Joint use of remote sensing data and volunteered geographic information for exposure estimation: Evidence from Valparaíso, Chile. *Natural Hazards*, *86*(S1), 81–105. https://doi.org/10.1007/s11069-016-2663-8

Geiß, C. & Taubenböck, H. (2013). Remote sensing contributing to assess earthquake risk: From a literature review towards a roadmap. *Natural Hazards*, *68*(1), 7–48. https://doi.org/10.1007/s11069-012-0322-2

Geiß, C. & Taubenböck, H. (2017). One step back for a leap forward: Toward operational measurements of elements at risk. *Natural Hazards*, *86*(S1), 1–6. https://doi.org/10.1007/s11069-017-2742-5

Goldblatt, R., Jones, N., Mannix, J. (2020). Assessing OpenStreetMap Completeness for Management of Natural Disaster by Means of Remote Sensing: A Case Study of Three Small Island States (Haiti, Dominica and St. Lucia). *Remote Sensing*, *12*(1), 118. https://doi.org/10.3390/rs12010118

Halls, J. & Magolan, J. (2019). A Methodology to Assess Land Use Development, Flooding and Wetland Change as Indicators of Coastal Vulnerability. *Remote Sensing*, *11*(19), 2260. https://doi.org/10.3390/rs11192260

Helmi, H., Basri, H., Sufardi, S., Helmi, H. (2019). Flood vulnerability level analysis as a hydrological disaster mitigation effort in Krueng Jreue Sub-Watershed, Aceh Besar, Indonesia. *Jàmbá Journal of Disaster Risk Studies*, *11*(1). https://doi.org/10.4102/jamba.v11i1.737

Herrmann, S. M., Sall, I., Sy, O. (2014). People and pixels in the Sahel: A study linking coarse-resolution remote sensing observations to land users' perceptions of their changing environment in Senegal. *Ecology and Society*, *19*(3). https://doi.org/10.5751/ES-06710-190329

Imran, M. et al. (2019). Mapping flood vulnerability from socioeconomic classes and GI data: Linking socially resilient policies to geographically sustainable neighborhoods using PLS-SEM. *International Journal of Disaster Risk Reduction*, *41*. https://doi.org/10.1016/j.ijdrr.2019.101288

International Federation of Red Cross and Red Crescent Societies. (2016). *World disasters report 2016: Resilience : saving lives today, investing for tomorrow*. International Federation of Red Cross and Red Crescent Societies.

Jazouli, A. et al. 2019). Remote sensing and GIS techniques for prediction of land use land cover change effects on soil erosion in the high basin of the Oum Er Rbia River (Morocco). *Remote Sensing Applications: Society and Environment*, *13*, 361–374. https://doi.org/10.1016/j.rsase.2018.12.004

Jensen, S. et al. (2015). The Emergence of a Globalized System for Disaster Risk Management and Challenges for Appropriate Governance. *International Journal of Disaster Risk Science*, *6*(1), 87–93. https://doi.org/10.1007/s13753-015-0043-8

Jiang, W. et al. (2017). Ongoing Conflict Makes Yemen Dark: From the Perspective of Nighttime Light. *Remote Sensing*, *9*(8). https://doi.org/10.3390/rs9080798

Joseph, O. et al. (2018). Desertification risk analysis and assessment in Northern Nigeria. *Remote Sensing Applications: Society and Environment*, *11*, 70–82. https://doi.org/10.1016/j.rsase.2018.04.012

Kaiser, G. et al. (2013). Mapping tsunami impacts on land cover and related ecosystem service supply in Phang Nga, Thailand. *Natural Hazards and Earth System Sciences*, *13*(12), 3095–3111. https://doi.org/10.5194/nhess-13-3095-2013

Kaku, K. (2019). Satellite remote sensing for disaster management support: A holistic and staged approach based on case studies in Sentinel Asia. *International Journal of Disaster Risk Reduction*, *33*, 417–432. https://doi.org/10.1016/j.ijdrr.2018.09.015

Kim, Donghwan, et al. (2020). Monitoring River Basin Development and Variation in Water Resources in Transboundary Imjin River in North and South Korea Using Remote Sensing. *Remote Sensing*, *12*(1), 195. https://doi.org/10.3390/rs12010195

Kim, Dongkyun et al. (2019). Advances in Remote Sensing to Understand Extreme Hydrological Events. *Advances in Meteorology*, *2019*, 1–2. https://doi.org/10.1155/2019/8235037

Komolafe, A., Herath, S., Avtar, R. (2018). Methodology to Assess Potential Flood Damages in Urban Areas under the Influence of Climate Change. *Natural Hazards Review*, *19*(2), 05018001. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000278

Kranz, O., Sachs, A., Lang, S. (2015). Assessment of environmental changes induced by internally displaced person (IDP) camps in the Darfur region, Sudan, based on multitemporal MODIS data. *International Journal of Remote Sensing*, *36*(1), 190–210. https://doi.org/10.1080/01431161.2014.999386

Kranz, O. et al.. (2018). Earth observation based multi-scale assessment of logging activities in the Democratic Republic of the Congo. *ISPRS Journal of Photogrammetry and Remote Sensing*, *144*, 254–267. https://doi.org/10.1016/j.isprsjprs.2018.07.012

Lang, S. et al. (2019). Earth observation tools and services to increase the effectiveness of humanitarian assistance. *European Journal of Remote Sensing*, 1–19. https://doi.org/10.1080/22797254.2019.1684208

Lang, S., Füreder, P., Rogenhofer, E. (2018). Earth Observation for Humanitarian Operations. In C. Al-Ekabi & S. Ferretti (Eds.), *Yearbook on Space Policy 2016*, 217–229. https://doi.org/10.1007/978-3-319-72465-2_10

Lang, S. et al. 2010). Earth observation (EO)-based *ex post* assessment of internally displaced person (IDP) camp evolution and population dynamics in Zam Zam, Darfur. *International Journal of Remote Sensing*, *31*(21), 5709–5731. https://doi.org/10.1080/01431161.2010.496803

Le Masson, V. (2015). Considering Vulnerability in Disaster Risk Reduction Plans: From Policy to Practice in Ladakh, India. *Mountain Research and Development*, *35*(2), 104–114. https://doi.org/10.1659/MRD-JOURNAL-D-14-00086.1

Leidig, M., Teeuw, R. M., Gibson, A. D. (2016). Data poverty: A global evaluation for 2009 to 2013 - implications for sustainable development and disaster risk reduction. *International Journal of Applied Earth Observation and Geoinformation*, *50*, 1–9. https://doi.org/10.1016/j.jag.2016.03.001

Lorenzo-Alonso, A. et al. (2019). Earth Observation Actionable Information Supporting Disaster Risk Reduction Efforts in a Sustainable Development Framework. *Remote Sensing*, *11*(1), 49. https://doi.org/10.3390/rs11010049

Mavhura, E. (2019). Systems Analysis of Vulnerability to Hydrometeorological Threats: An Exploratory Study of Vulnerability Drivers in Northern Zimbabwe. *International Journal of Disaster Risk Science*, *10*(2), 204–219. https://doi.org/10.1007/s13753-019-0217-x

Michellier, C. et al. (2020). Evaluating population vulnerability to volcanic risk in a data scarcity context: The case of Goma city, Virunga volcanic province (DR Congo). *International Journal of Disaster Risk Reduction*, *45*. https://doi.org/10.1016/j.ijdrr.2019.101460

Mind'je, R. et al. (2019). Flood susceptibility modeling and hazard perception in Rwanda. *International Journal of Disaster Risk Reduction*, *38*. https://doi.org/10.1016/j.ijdrr.2019.101211

Mohamed, S., & El-Raey, M. (2019). Vulnerability assessment for flash floods using GIS spatial modeling and remotely sensed data in El-Arish City, North Sinai, Egypt. *Natural Hazards*, *96*(3). https://doi.org/10.1007/s11069-019-03571-x

Mojaddadi, H. et al. 2017). Ensemble machine-learning-based geospatial approach for flood risk assessment using multi-sensor remote-sensing data and GIS. *Geomatics, Natural Hazards and Risk*, *8*(2), 1080–1102. https://doi.org/10.1080/19475705.2017.1294113

MunichRE. (2018). *A stormy year. TOPICS Geo Natural Catastrophes 2017.* https://www.munichre.com/content/dam/assets/munichre/content-pieces/ documents/pdf/302-09092_en.pdf

Murad, C. A., & Pearse, J. (2018). Landsat study of deforestation in the Amazon region of Colombia: Departments of Caquetá and Putumayo. *Remote Sensing Applications: Society and Environment*, *11*, 161–171. https://doi.org/10.1016/j.rsase.2018.07.003

NASA (2020). EARTHDATA. Powered by EOSDIS. What is Remote Sensing? *The National Aeronautics and Space Administration*. https://earthdata.nasa.gov/learn/remote-sensing

NASA (2019). *NASA Disasters Program 2018 Annual Summary*. NASA Earth Science. Reports. https://disasters.nasa.gov/reports

Nero, B. F. (2017). Urban green space dynamics and socio-environmental inequity: Multi-resolution and spatiotemporal data analysis of Kumasi, Ghana. *International Journal of Remote Sensing*, *38*(23), 6993–7020. https://doi.org/10.1080/01431161.2017.1370152

Ntajal, J. et al. (2017). Flood disaster risk mapping in the Lower Mono River Basin in Togo, West Africa. *International Journal of Disaster Risk Reduction*, *23*, 93–103. https://doi.org/10.1016/j.ijdrr.2017.03.015

ODI. (2019). *Disaster risk reduction in conflict contexts. An agenda for action* (Overseas Development Institute, Federal Ministry for Economic Cooperation and Development (BMZ), & Deutsche Gesellschaft fuer Internationale Zusammenarbeit (giz) GmbH, Eds.). Overseas Development Institute. https://www.odi.org/features/when-disasters-and-conflict-collide

ODI, & World Bank. (2015). *The Tripple Dividend of Resilience. Realising development goals through the multiple benefits of disaster risk management*.

OECD (2018). *States of fragility 2018*. OECD iLibrary. https://doi.org/10.1787/9789264302075-en

Pangali Sharma, T. et al. (2019). Review of flood disaster studies in Nepal: A remote sensing perspective. *International Journal of Disaster Risk Reduction*, *34*, 18–27. https://doi.org/10.1016/j.ijdrr.2018.11.022

Pirasteh, S., & Li, J. (Eds.). (2017). *Global Changes and Natural Disaster Management: Geo-information Technologies*. Springer International Publishing. https://doi.org/10.1007/978-3-319-51844-2

Pollock, W. et al. (2019). Risk at the margins: A natural hazards perspective on the Syrian refugee crisis in Lebanon. *International Journal of Disaster Risk Reduction*, *36*, 101037. https://doi.org/10.1016/j.ijdrr.2018.11.026

Post, J. et al. (2017). Some remarks on making remote sensing-based mapping of elements at risk usable in international development cooperation. *Natural Hazards*, *86*(S1), 189–191. https://doi.org/10.1007/s11069-016-2656-7

Pradhan, B. et al. (2011). Landslide hazard and risk analyses at a landslide prone catchment area using statistical based geospatial model. *International Journal of Remote Sensing*, *32*(14), 4075–4087. https://doi.org/10.1080/01431161.2010.484433

Rafiq, L., Blaschke, T., Zeil, P. (2010). Application of satellite derived information for disaster risk reduction: Vulnerability assessment for southwest coast of Pakistan. *Proc. SPIE 7831*, *Earth Resources and Environmental Remote Sensing/GIS Applications*. Toulouse, France. https://doi.org/10.1117/12.864858

Rahman, Md. S., & Di, L. (2017). The state of the art of spaceborne remote sensing in flood management. *Natural Hazards*, *85*(2), 1223–1248. https://doi.org/10.1007/s11069-016-2601-9

Ranke, U. (2016). *Natural Disaster Risk Management*. Springer International Publishing. https://doi.org/10.1007/978-3-319-20675-2

Rao, S. (2013). Disaster risk governance at national and sub-national levels. *GSDRC Helpdesk Research Report 991*. http://www.gsdrc.org/go/display&type=Helpdesk&id=991

Reportlinker. (2019). *Global earth observation satellite, data and service market generated $7.17 billion in 2018 and is estimated to grow at a CAGR of 9.10% during 2018-2023*. https://www.prnewswire.com/news-releases/global-earth-observation-satellite-data-and-service-market-generated-7-17-billion-in-2018-and-is-estimated-to-grow-at-a-cagr-of-9-10-during-2018-2023--300837805.html

Römer, H. et al. (2012). Potential of remote sensing techniques for tsunami hazard and vulnerability analysis – a case study from Phang-Nga province, Thailand. *Natural Hazards and Earth System Science*, *12*(6), 2103–2126. https://doi.org/10.5194/nhess-12-2103-2012

Sahana, M., & Sajjad, H. (2019). Vulnerability to storm surge flood using remote sensing and GIS techniques: A study on Sundarban Biosphere Reserve, India. *Remote Sensing Applications: Society and Environment*, *13*, 106–120. https://doi.org/10.1016/j.rsase.2018.10.008

Salami, R. O., von Meding, J. K., & Giggins, H. (2017). Urban settlements' vulnerability to flood risks in African cities: A conceptual framework. *Jàmbá: Journal of Disaster Risk Studies*, *9*(1). https://repository.nwu.ac.za/handle/10394/25236

Shaw, R., Izumi, T., & Shi, P. (2016). Perspectives of Science and Technology in Disaster Risk Reduction of Asia. *International Journal of Disaster Risk Science*, *7*(4), 329–342. https://doi.org/10.1007/s13753-016-0104-7

Shepherd et al. (2017). *Trends in poverty and inequality and further clustering of developing countries. Challenges and opportunities for development policy: Final report* (European Commission, Ed.). EU Publications.

Shi, P. & Jaeger, C. (2019). *Disaster Risk Science*. Springer Singapore. Beijing, China & Potsdam, Germany. https://doi.org/10.1007/978-981-13-6689-5

Shi, P. et al. (2017). Green Development and Integrated Risk Governance. *International Journal of Disaster Risk Science*, *8*(2), 231–233. https://doi.org/10.1007/s13753-017-0133-x

Skakun, S. et al. (2014). Flood Hazard and Flood Risk Assessment Using a Time Series of Satellite Images: A Case Study in Namibia: Flood Hazard and Flood Risk Assessment. *Risk Analysis*, *34*(8), 1521–1537. https://doi.org/10.1111/risa.12156

tagesschau.de. (2020). *Coronavirus: Profitiert der Klimaschutz von der Krise?* tagesschau.de. https://www.tagesschau.de/faktenfinder/coronavirus-auswirkungen-klima-101.html

Thenkabail, P. S. (2016). *Remote sensing handbook*. Vol. 3. CRC Press. Routledge, Taylor & Francis Group. Boca Raton | London | New York. https://www.taylorfrancis.com/books/9781482217872

Thompson, D. (2019). *Disaster risk governance: Four cases from developing countries*. Routledge, Taylor & Francis Group. Boca Raton | London | New York.

Tierney, K. (2012). Disaster Governance: Social, Political and Economic Dimensions. *Annual Review of Environment and Resources*, *37*(1), 341–363. https://doi.org/10.1146/annurev-environ-020911-095618

UNDRR (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030.* https://www.undrr.org/implementing-sendai-framework/what-sf

UNDRR (2019). *Global Assessment Report on Disaster Risk Reduction 2019*. United Nations 2019. https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019

UNDRR (2020a). *PreventionWeb — Managed by the UN Office for Disaster Risk Reduction (UNDRR). Disaster risk reduction & disaster risk management.* https://www.preventionweb.net/risk/drr-drm

UNDRR (2020b). *UN Office for Disaster Risk Reduction. Terminology. Disaster risk reduction.* https://www.undrr.org/terminology

von Uexkull, N. et al. (2016). Civil conflict sensitivity to growing-season drought. *Proceedings of the National Academy of Sciences*, *113*(44), 12391–12396. https://doi.org/10.1073/pnas.1607542113

Wang, B. et al. (2013). Problems from Hell, Solution in the Heavens? Identifying Obstacles and Opportunities for Employing Geospatial Technologies to Document and Mitigate Mass Atrocities. *Stability: International Journal of Security & Development*, *2*(3). https://doi.org/10.5334/sta.cn

Wang, J.-F., & Li, L.-F. (2008). Improving Tsunami Warning Systems with Remote Sensing and Geographical Information System Input. *Risk Analysis*, *28*(6), 1653–1668. https://doi.org/10.1111/j.1539-6924.2008.01112.x

Welthungerhilfe. (2007). *Orientierungsrahmen Konfliktsensibles Handeln in der Auslandsarbeit*. Welthungerhilfe. https://www.welthungerhilfe.de/fileadmin/pictures/publications/de/project_and_professional_papers/2007_fachkonzept_orientierungsrahmen_konfliktsensibles_handeln_auslandsarbeit.pdf

Willroth, P., Kaiser, G., Vafeidis, A. T., Ludwig, R., Sterr, H., & Revilla Diez, J. (2012). Potential of remote sensing techniques for tsunami hazard and vulnerability analysis—A case study from Phang-Nga province, Thailand. *Gale In Context: Environmental Studies*, *12*(6), 2103.

Wisner, B., et al. (2004). *At Risk: Natural hazards, people's vulnerability and disasters. Second edition*. Routledge, Taylor & Francis Group. Boca Raton | London | New York.

Wu, J. et al. (2018). Development of an Asset Value Map for Disaster Risk Assessment in China by Spatial Disaggregation Using Ancillary Remote Sensing Data: Asset Value Map for Disaster Risk Assessment. *Risk Analysis*, *38*(1), 17–30. https://doi.org/10.1111/risa.12806

Yue, X. et al. (2018). Risk Identification of Seismic Landslides by Joint Newmark and RockFall Analyst Models: A Case Study of Roads Affected by the Jiuzhaigou Earthquake. *International Journal of Disaster Risk Science*, *9*(3), 392–406. https://doi.org/10.1007/s13753-018-0182-9