# University of Southampton

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Geography and Environmental Science

**Socio-economic, infrastructural and environmental development and speed of post-disaster recovery in the Kendrapara District of Odisha, India**

Volume 1 of 1

by

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# Abstract

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**Socio-economic, infrastructural and environmental development and speed of post-disaster recovery in the Kendrapara District of Odisha, India**

Margherita Fanchiotti

Disasters and development are closely intertwined. This is because development changes can increase or decrease vulnerabilities and capacities in the face of disasters, just like disasters can destroy development efforts or create development opportunities. These links become particularly evident in the post-disaster recovery phase, when rehabilitation and reconstruction can shape future development. Recovery, however, is one of the least studied phases of the disaster risk reduction cycle and the question of which attributes lead to quicker or slower recovery remains uncertain.

The Indian state of Odisha is highly prone to tropical cyclones, with the most intense recorded event being the 1999 Odisha Super Cyclonic Storm. Twenty years later, there is still no comprehensive documentation of the losses caused by the cyclone or evaluation of the extent or speed of recovery from the event. This research contributes to enhancing the understanding of how socio-economic, environmental and infrastructural development changes can result in differential post-disaster recovery rates and how different associates of development interact and contribute to speed of recovery in local communities. An innovative mixed methods approach is used (including a systematic review, statistical analysis, remote sensing techniques, focus group discussions and semi-structured interviews) to assess socio-economic, infrastructural and environmental pre-disaster conditions and their relation to speed of recovery. This thesis provides: a comprehensive assessment of documented losses caused by the 1999 Odisha Super Cyclonic Storm; an evaluation of differential recovery over space and time; an assessment of developmental 'hotspots' (where recovery exceeded expectation) and 'coldspots' (where there was delayed recovery) for the Kendrapara District of Odisha.

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# DECLARATION OF AUTHORSHIP

I, Margherita Fanchiotti, declare that this thesis and the work presented in it is my own and has been generated by me as the result of my own original research.

Socio-economic, infrastructural and environmental development and speed of post-disaster recovery in the Kendrapara District of Odisha, India

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
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3. Where I have consulted the published work of others, this is always clearly attributed;
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# Definitions and Abbreviations

| | |
|---|---|
| ADPC | Asian Disaster Preparedness Centre |
| CEOS | Committee on Earth Observation Satellites |
| CMC | Cyclone Management Committee |
| CRED | Centre for Research on the Epidemiology of Disasters |
| DFID | Department for International Development |
| FAO | Food and Agriculture Organization |
| FGD | Focus group discussion |
| GDP | Gross Domestic Product |
| GSDP | Gross State Domestic Product |
| HFL | High Flood line |
| IMD | India Meteorological Department |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NDVI | Normalised Difference Vegetation Index |
| NIDM | National Institute of Disaster Management |
| NREGA | National Rural Employment Guarantee Act |
| NSDP | Net State Domestic Product |
| OSDMA | Odisha State Disaster Management Authority |
| PDNA | Post-Disaster Needs Assessment |
| PDS | Public Distribution System |
| PRA | Participatory Rural Appraisal |
| SC 1999 | Super Cyclone 1999 |
| SC | Scheduled Caste |
| SDG | Sustainable Development Goal |
| ST | Scheduled Tribe |
| UN | United Nations |
| UNDRR | United Nations Office for Disaster Risk Reduction (formerly, UNISDR) |
| UNISDR | United Nations International Strategy for Disaster Reduction |

| | |
|---|---|
| USGS | United States Geological Survey |
| WMO | World Meteorological Organization |

# Chapter 1: Introduction

## 1.1 Overview

Despite global development gains, over 130 million people are still in need of humanitarian assistance worldwide (United Nations, 2019a). While the primary drivers of humanitarian situations remain political, disasters caused by natural hazards, human-induced hazards or a combination of both continue to cause significant losses every year worldwide, often undermining decades of development efforts in just a few hours (UNISDR, 2019; United Nations, 2019b).

According to the United Nations Office for Disaster Risk Reduction (UNDRR), disasters caused recorded economic losses up to 2.9 trillion US dollars over the past decade (1998-2017) (CRED & UNDRR, 2018). Of these, 77% were due to climate-related events (ibid.). The human cost of disasters is found to overwhelmingly affect lower income countries, with people in poorest areas on average six times more likely to be negatively impacted (ibid.).

It is well recognised that the disaster and development discourses are closely intertwined (Collins, 2009; Mochizuki et al., 2014a). Disasters can exacerbate existing vulnerabilities, contribute to stagnant or negative development rates and lead to significant socio-economic setbacks (A.E. Collins, 2009, 2013). Similarly, post-disaster recovery requires social, environmental and infrastructural sustainability (Andrew E Collins, 2018). Exposure to disasters is increasing under factors such as climate change, rising urbanisation and overpopulation, which will only contribute to further exposing the macro-level nexus between disasters and development (Mochizuki et al., 2014a).

The importance of jointly addressing disasters and development issues has been identified as a global priority, as reflected in all major international agreements, from the Sustainable Development Goals (SDGs) (United Nations, 2015c) to the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015b), the Paris Agreement (United Nations, 2015b), the Agenda for Humanity (United Nations, 2016a) and the Addis Ababa Action Agenda (United Nations, 2015a).

Great emphasis has been placed on strengthening the humanitarian-development nexus, reflecting the urgency to meet needs while reducing risk, vulnerabilities and exposure (United Nations, 2016b). This has been translated in the notion of 'collective outcomes' (ibid.) and becomes especially apparent in the post-disaster recovery phase as the bridge between emergency relief efforts and preparedness for future events. Concepts such as those of 'build back better' or 'new normal' have emerged, intrinsically linking the disaster risk management and development narratives (UNISDR, 2015b).

However, the actual and perceived nature of the linkages between development changes and post-disaster recovery remains contested (A.E. Collins, 2018; Mochizuki et al., 2014a; Weichselgartner & Kelman, 2015). There is limited empirical and analytical evidence of these interactions (A.E. Collins, 2018). There exist only few methodologies to investigate post-recovery rates based on sets of development indicators, which are predominantly suitable for data-rich contexts and often fail to capture local perspectives (Mochizuki et al., 2014a; Weichselgartner & Kelman, 2015). As a result, there continue to be theoretical, methodological and empirical gaps that hamper our understanding of the disaster-development nexus (A.E. Collins, 2018; Mochizuki et al., 2014a).

This thesis contributes to this knowledge gap, drawing evidence from one of the worst tropical cyclones in history as a case study, using a novel mixed methods approach.

## 1.2 Disasters and development in Odisha, India

India has been ranked among the top ten countries in the world in terms of cumulative disaster losses between 1998 and 2017, totalling 79.5 billion US dollars (CRED & UNDRR, 2018). It is also the only low-income nation among these, placed fourth after the US, Japan and China (ibid.). The large majority of these losses in India relate to tropical cyclones and flooding, which affect the largest number of people across the globe too (CRED & UNDRR, 2018; Emanuel, 2003).

Vulnerability to tropical cyclones is particularly significant in deltaic regions, which combine complex natural and human systems in low-lying coastal landforms and are, thus, particularly sensitive to climatic stresses (Wong et al., 2014; Woodruff, Irish, & Camargo, 2013). In India, the Mahanadi delta is located in the state of Odisha, which presents a long record of cyclonic storms (cf. Chittibabu et al., 2004).

According to the India Meteorological Department (IMD), the most intense recorded cyclone on India's coasts is the 1999 Odisha Super Cyclone (also known as SC 1999), which made landfall near the coastal town of Paradip in October 1999, followed by Cyclone Phailin, which crossed Odisha and its neighbouring state of Andra Pradesh in October 2013 (IMD, 2013).

The establishment of the Odisha State Disaster Management Authority (OSDMA) under the provisions of the 2005 Disaster Management Act, as well as major investments in the disaster risk management system at the state level (i.e. the construction of flood protection structures and cyclone shelters) in the aftermath of SC 1999 have led to a significant decrease in disaster mortality. From 9,893 fatalities caused by SC 1999 (NIDM, 2013), figures went down to 44 lost lives in Odisha as a consequence of Cyclone Phailin (NIDM, 2013). As a result, Odisha was featured as a success story in the 2015 Global Assessment Report on Disaster Risk Reduction (UNISDR, 2015a).

In parallel, the country also experienced economic growth, with an economic expansion by 53% between 2011 and 2017 (Government of Odisha, 2017a, p. 2). However, agriculture continues to account for 62% of the workforce, which is an issue of concern in view of the sector's exposure to natural hazards (Government of Odisha, 2017b).

Despite the advances in disaster risk management, disasters caused by natural hazards continue to pose a significant threat to the State's economy, resulting in loss of livelihoods and significant damages. For instance, Cyclone Phailin affected a population of over 12 million and damaged farmland in Odisha was estimated at close to 670 thousand ha in 2013 (IMD, 2013). One year later, Cyclone HudHud caused the loss of 46 human lives, while over 135 thousand people were evacuated by the authorities following advance warnings released by IMD; more than 2 million ha of farmland were heavily damaged (Times of India, 2014).

Records, therefore, suggest that successful emergency management practices allowed for significant improvements over the past twenty years, leading to reduced disaster mortality. However, economic losses continue to adversely impact the state.

Furthermore, twenty years after SC 1999, there is still no comprehensive record of losses at the village level, nor any evidence of how differential post-disaster recovery rates may have interplayed with development and subsequent natural hazards. This gap, which is not only relevant for Odisha but also for disaster-prone developing countries worldwide, guided the development of the aim of this thesis.

## 1.3 Research aim

The aim of this research study is to characterise the relationship between pre-disaster socio-economic, infrastructural and environmental development with the rate and type of post-disaster recovery at the community level.

## 1.4 Research objectives

This study seeks to address the aim through the following research objectives:

I) Identify socio-economic, environmental and infrastructural losses caused by the 1999 Super Cyclonic Storm in the study site.

II) Map socio-economic, environmental and infrastructural development changes through time in the study site and identify hotspots/coldspots.

III) Estimate differential post-disaster recovery rates, identify recovery hotspots/coldspots, and compare them with socio-economic, environmental and infrastructural development hotspots/coldspots.

IV) Compare and contrast community perceptions of socio-economic, environmental and infrastructural development changes and their implications for post-disaster recovery.

## 1.5 Innovation

The innovation of this research lies in its contribution to enhancing the understanding of how socio-economic, environmental and infrastructural development changes can result in differential post-disaster recovery rates and how these socio-economic, environmental and infrastructural development attributes are perceived to interact and contribute to speed of recovery by local communities.

An innovative approach consisting in the use of mixed methods, including a systematic review, statistical analysis, satellite remote sensing techniques, focus group discussions and semi-structured interviews, is used to assess socio-economic, infrastructural and environmental pre-disaster conditions and their relationship with speed of recovery.

Unlike most frameworks for post-disaster recovery assessment which consist of a series of indicators arguably subjectively selected by experts and mostly referring to the sphere of development, with no clear evidence of their relation with recovery, this research study adopts a data-driven approach to explore socio-economic, environmental and infrastructural development changes and recovery rates, letting communities at risk define the association between socio-economic, environmental and infrastructural development and post-disaster recovery according to their experience and perceptions.

In doing so, it relies on data and local knowledge to present case studies that contribute to the characterisation of recovery through practical evidence. As a result, it provides a comprehensive assessment of the damages caused by the 1999 Odisha Super Cyclonic Storm that has never been undertaken before and a proxy evaluation of the status of recovery over time and through subsequent natural hazards in the Kendrapara District of Odisha.

## 1.6 Thesis structure

This report is articulated into eight chapters. This first chapter presents the research aim, objectives and justification. The thesis that follows cover the following sections: literature review, methodology, four substantive chapters and the conclusions. This section gives a brief overview of the content of each of these chapters.

### 1.6.1 Literature review

Chapter 2 gives an overview of the literature that has been reviewed and deemed essential for the study. It first discusses the global disaster risk reduction context. It then provides a theoretical foundation on the relationship between disasters and development. Literature on post-disaster recovery is later explored. Finally, the chapter discusses the use of census and satellite remote sensing data to understand changes in development and disasters. It concludes by looking at disasters, development and post-disaster recovery in the Kendrapara District of Odisha, India.

### 1.6.2 Methodology

Chapter 3 presents the overarching research design and includes a brief description of the rationale for adopting a data-driven, mixed methods approach. It introduces the conceptual framework of this thesis and outlines the methods used in this research, covering a mix of quantitative and qualitative approaches. This, notably, includes a systematic review, satellite remote sensing techniques, statistical analysis and social research methods such as key informant interviews, focus group discussions and participatory mapping exercises.

This chapter only provides a methodological overview and does not provide the technical aspects of the various methods applied; these details are reserved for the substantive chapters themselves in order to provide a more logical flow.

### 1.6.3 Substantive Chapters

There are four substantive chapters to this thesis, each contributing to one of the four research objectives of this study. Each chapter is presented loosely in the format of an academic journal paper.

Chapter 4 provides results of a systematic review of documented losses caused by the 1999 Odisha Super Cyclonic Storm (research objective 1). It provides the context and a baseline of information available for the analysis in the later chapters of this thesis.

Chapter 5 delivers the findings of the data-driven analysis that has been conducted to explore past socio-economic, environmental and infrastructural developmental gains and losses in the study site and to identify hotspots/coldspots where to further investigate the links between socio-economic, environmental and infrastructural development and post-disaster recovery (research objective 2).

Chapter 6 discusses differential post-disaster recovery rates estimated using proxies from satellite earth observation through space and time and identifies recovery hotspots/coldspots. It then analyses trends and patterns of post-disaster recovery rates in previously mapped socio-economic, environmental and infrastructural development hotspots/coldspots (research objective 3).

Chapter 7 explains the results of the qualitative work undertaken to investigate community perceptions of socio-economic, environmental and infrastructural changes and their impact on post-disaster recovery (research objective 4).

#### 1.6.4 Conclusions

Chapter 8 summarises the findings of this study, discusses its novel contributions to knowledge, outlines its limitations and presents implications for future research and policy.

# Chapter 2: Literature review

## 2.1 Introduction

This chapter provides an overview of the literature deemed essential for this research study. It is divided into the following sections, after this introduction: 2.2. Global disaster risk reduction context; 2.3. Disasters and development; 2.4. Post-disaster recovery; 2.5. The use of census and remote sensing data to understand changes in development and disasters; 2.6 Disasters and development in the Kendrapara District of Odisha, India; and 2.7 Understanding socio-economic, infrastructural and environmental development and post-disaster recovery in the Kendrapara District of Odisha, India.

The first section describes the global disaster risk reduction context, as well as its historical evolution over the past decades. The second section summarises the current understanding of the mutual relationships between disasters and development. The third section offers an introduction to the concept of post-disaster recovery, moving from theory to assessment and measurement, in line with the international agenda and across the academic, practitioners' and policy makers' communities. The fourth section explains how socio-economic data recorded from national census as well as satellite remote sensing data have been beneficial in investigating changes associated to development and disaster risk reduction. The fifth section provides an overview of the case study area, investigating the exposure of local communities to tropical cyclones and other natural hazards, the current economic development situation in the area and its evolution over time in relation to disasters, poverty issues and safety nets, in connection with disaster risk reduction. The sixth section concludes by discussing the benefits and challenges of investigating socio-economic, infrastructural and environmental development and post-disaster recovery in the study site.

## 2.2 Global disaster risk reduction context

Disasters induced by natural hazards affect millions of people every year worldwide, causing loss of life and estimated annual economic damages of 250-300 million dollars (UNISDR, 2015a). Exposure to these hazards is arguably increasing as extreme events are occurring more often due to climate change, and greater urbanisation is leading to higher concentrations of populations in exposed locations (Emanuel, 2005; UNISDR, 2015a; Wisner, Blaikie, Cannon, & Davis, 2003; WMO, 2006). In light of this, the concept of disaster risk reduction has become globally important, as highlighted in all major international initiatives, such as the 2030 Agenda for Sustainable Development (United

Nations, 2015c), the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015b), the Paris Agreement (United Nations, 2015b) and the Addis Ababa Action Agenda (United Nations, 2015a).

The United Nations Office for Disaster Risk Reduction (UNISDR) defines disaster as 'a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts' (United Nations, 2016c, p. 13), *disaster risk* as 'the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity' (United Nations, 2016c), and *disaster risk reduction* as 'the systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster' (UNISDR, 2009, pp. 10–11).

Definitions of the concept of disaster risk, however, have been discussed and re-formulated many times in the past decades. The earliest social models of disasters were linear in considering the human consequences of a disaster as the result of physical hazards univocally acting upon vulnerability and risk was conventionally framed mainly in physical terms (Alexander, 2013).

Later, however, the importance of accounting for a socio-scientific perspective of risk into disaster studies to understand the broad physical and social vulnerability of societies has been recognised (Alexander, 2013; Cutter, 1996; Cutter, Boruff, & Shirley, 2003; Hewitt.K, 1983; Kelman, 2010; O'Keefe, Westgate, & Wisner, 1976; Slovic, 1987; Starr, 1969).

The dominant viewpoint that considered disasters of natural origin as a mere consequence of extremes in physical phenomena 'rather than a combination of these extremes and failures in human systems' (Cutter, 1984, p. 226) was critiqued by Hewitt in his 'Interpretations of Calamity' (1983), where he argued the dominant role of vulnerability in disasters over the hazard component and pointed that different interpretations of disasters result from different social groups (Cutter, 1984; Hewitt, 1983).

Since then, the literature on vulnerability has grown significantly and so has research on disaster resilience and adaptation. These concepts have been theorised in many different ways across different disciplines and there continues to be little consensus on their characterisation, as well as on the articulation of the relationships between the three. Cutter et al. (2008) have captured the different interpretations of this interrelation that exist in the literature (Figure 2.1).

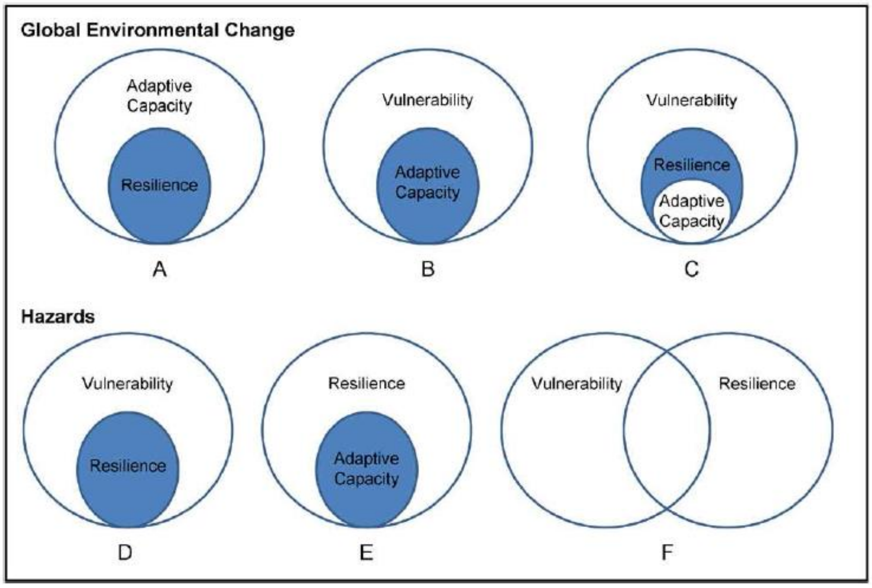


Figure 2.1: Summary of the different conceptual linkages between resilience, vulnerability and adaptive capacity that exist in the literature (Cutter et al., 2008)

While some authors consider resilience as a core component of adaptive capacity when looking at global environmental changes (Adger, 2006; Folke, 2006) as shown in Figure 2.1 A, others argue that adaptive capacity is nested in resilience and then further into vulnerability as in Figure 2.1 C (Gallopín, 2006). Finally, some interpret vulnerability as part of adaptive capacity (Figure 2.1 B) (I. Burton, Huq, Lim, Pilifosova, & Schipper, 2002; O'Brien et al., 2004; Smit, Burton, Klein, & Street, 1999). When exploring specifically the relation between resilience and vulnerability in the context of hazards, some view resilience as the flipside of vulnerability (Folke et al., 2002), while others argue that a system can still be vulnerable while being resilient and that the resilience discourse should move beyond vulnerability reduction (Manyena, 2006). Although there is some consensus on the fact that a resilient city or community is less vulnerable to natural hazards, the approach looking at resilience as the positive side of vulnerability has been labelled as a strategic approach to bring forward an optimistic and more appealing approach to disaster risk reduction to attract consensus (Manyena, 2006; Weichselgartner & Kelman, 2015). Resilience is seen as a component of vulnerability (Figure 2.1 D) by those authors who argue that it is an outcome rather than a process (Manyena, 2006) and, in the context of disaster risk reduction, resilience has also been considered as embedding adaptive capacity (Figure 2.2 E) (Bruneau et al., 2003; Tierney & Bruneau, 2007). Finally, many scientists view resilience and vulnerability as two separate concepts that present many common features (Figure 2.2 F) (Cutter et al., 2008).

There exist, therefore, many conflicting conceptualisations of the interactions between resilience, adaptive capacity and vulnerability, which build on existing controversies around the definitions of these concepts that remain unresolved.

Despite limited consensus on the theoretical interpretation of vulnerability, resilience and adaptation (Adger, 2000, 2006; Carpenter, Walker, Anderies, & Abel, 2001; Cutter et al., 2008; DFID, 2011; Folke, 2006; Manyena, 2006; Norris, Stevens, Pfefferbaum, Wyche, & Pfefferbaum, 2008; Tompkins & Adger, 2004, 2003), several efforts have been made to translate these descriptive concepts into policy and practice, first in the academia, then in communities of practitioners and finally on the international agenda.

In particular, the need to establish baselines against which to measure progress has been widely accepted by practitioners and policy makers worldwide, although the usefulness of the concepts of vulnerability, resilience and adaptation themselves and of their assessment continues to be highly debated in academic circles and elsewhere (Dauphiné & Provitolo, 2007; Kelman, Gaillard, & Mercer, 2015; Weichselgartner & Kelman, 2015).

This conflictual relationship between theory and practice has been seen by some as an opportunity for vulnerability, resilience and adaptation research to bring together theory and practice by contributing to gather evidence of what these concepts are in practical terms to inform their theoretical delineation (Dauphiné & Provitolo, 2007; Kelman et al., 2015; Weichselgartner & Kelman, 2015).

A notable recommendation is to include involved communities in research work for the co-generation of knowledge, as well as to raise awareness and promote ownership. Studies on risk perception, in particular, have highlighted how disaster risk is perceived differently by different social groups.

Studies on the social acceptance of risk have been pioneered by Starr and led the way to further research on risk perception: in his paper ‘Social Benefit versus Technological Risk’ (1969), he developed a methodology for revealing existing social preferences associated with a broad range of activities (e.g. driving, skiing, natural disasters, atomic power plants, etc.). This method implies that the society has reached an optimal balance between the social benefits and the social risks resulting from each activity (Slovic, 1987, p. 281), and it shows that risk acceptance is influenced by risk and benefit awareness (Starr, 1969, p. 1237).

Starr's research formed the basis for the development of the psychometric paradigm (Fischhoff, Slovic, & Lichtenstein, 1978), which creates cognitive maps of people's perceptions of risk (Fischhoff et al., 1978; Slovic, 1987).

In his paper 'Perception of Risk' (1987), Slovic discusses some of the results obtained from psychometric studies to make the fundamental assumption that, in order for policies to be effective, decision-makers need to understand how people evaluate risk and to conclude that, while 'lay people sometimes lack certain information about hazards', 'their basic conceptualization of risk is much richer than that of experts and reflects legitimate concerns that are typically omitted from expert risk assessments' (Slovic, 1987, p. 285).

The idea of a mutual contribution between experts and lay people lies at the core of community-based disaster risk reduction, which combines scientific expertise and community participation to promote successful disaster risk reduction (Chambers, 2007b; Kulatunga, Zaman, Biswas, Parvez, & Amaratunga, 2010; Pelling, 2007; van Aalst, Cannon, & Burton, 2008).

The Asian Disaster Preparedness Centre (ADPC) defines *community-based disaster risk management* as 'a process of disaster risk management in which communities at risk are actively engaged in the identification, analysis, treatment, monitoring and evaluation of disaster risks in order to reduce their vulnerabilities and enhance their capacities' (Abarquez & Murshed, 2004, p. 9). Being 'at the frontline of disasters' (Murase, Tyagi, Saalmueller, & Nagata, 2008, p. 9), communities therefore become the spatial unit of community-based disaster risk reduction, which makes use of bottom-up approaches to overcome the limitations of traditional top-down approaches that often ignore local capacities and fail to address local needs (Murase et al., 2008; van Aalst et al., 2008).

A community-based approach to risk reduction can help to deliver on ground impact, to improve risk communication and to locally arrest risk accumulation (Anderson & Holcombe, 2013), and it is a notable recommendation for developing countries (Abarquez & Murshed, 2004; ADPC, 2005; UNISDR, 2006). Community-based disaster risk reduction relies on participatory methods, which have evolved over recent decades and of which Chambers has been one of the pioneers (Chambers, 1994, 2007b, 2007a). Community-based disaster risk reduction may as well draw upon what has been defined as *citizen science* (Cohn, 2008; Silvertown, 2009), i.e. 'the scientific activities in which non-professional scientists volunteer to participate in data collection, analysis and dissemination of a scientific project' (Haklay, 2013, p. 106).

Building on academic work, international organisations and supra-national research centres have significantly contributed to promoting community-based disaster risk reduction and to codifying frameworks which reflect the mainstream approaches emerging from available scientific literature, with the ultimate scope of facilitating its implementation at the operational level by field practitioners (Abarquez & Murshed, 2004; Murase et al., 2008; World Bank, 1996).

Participatory methods for the assessment of hazards, vulnerabilities and capacities at the community scale are used by non-governmental organisations (NGOs) and community-based organisations (van Aalst et al., 2008), and recent international policy changes opened the way for strategic inclusion of results of participatory approaches into national and international development policy making (DFID, 2006; Pelling, 2007, p. 373).

## 2.3 Disasters and Development

Disaster risk reduction has been at the core of the international agenda as reflected in the past three World Conferences on Disaster Risk Reduction and their outcome documents, the latest of which is the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015b). At the same time and ever since the Brundtland Report in 1987 (United Nations, 1987), there has been a global call for sustainable development. The need to re-examine the global challenges for development and to propose realistic solutions to them has been the subject of international efforts over the past thirty years, with a focus on the critical environmental issues that our society is facing (United Nations, 1987).

While the discourses of sustainable development and disaster risk reduction present many common opportunities and challenges, as highlighted in the 2030 Agenda (United Nations, 2015c), which acknowledges disaster risk reduction as a cross-cutting issue playing a fundamental role for the achievement of most of the SDGs (cf. SGDs 1, 2, 4, 9, 11, 13, 15, 16 and 17), these two disciplines have mostly been treated separately.

The links between development and disasters have been the subject of a large body of literature (A.E. Collins, 2009; Pelling, 2003; Schipper & Pelling, 2006; White et al., 2005). These studies suggest that development significantly contributes to shaping the way in which people cope with natural hazards and that sustainable development and disaster risk reduction should, therefore, be pursued together (A.E. Collins, 2009; Schipper & Pelling, 2006; White et al., 2005). This is because development changes can increase or decrease vulnerabilities and coping capacities, just like disasters can destroy development efforts or create development opportunities, for example for building back better (A.E. Collins, 2009; Goldschmidt & Kumar, 2016; UNISDR, 2015a).

There is evidence, in particular, that economic development can help reduce the death toll after a disaster and that, by addressing the root causes of vulnerability, development initiatives have the potential to enhance individual and community capacities for withstanding disasters (Goldschmidt & Kumar, 2016; Kahn, 2005).

Similarly, other studies argue that the discourses of development and disaster risk reduction adopt similar methods and approaches, and are therefore closely related (Barrett & Constas, 2014). These studies particularly argue that an understanding of the institutional, environmental, socio-economic and other development incentives and constraints that regulate an individual's or a community's wellbeing shape their resilience to natural hazards (Barrett & Constas, 2014). Human wellbeing has been argued to be both a cause and consequence of both disaster and development, in that communities become more resilient to natural hazards by securing livelihoods, demanding rights, managing risks and adapting to natural hazards (A.E. Collins, 2009). These studies prove that good governance can help in enhancing community resilience to natural hazards and suggest investing in community wellbeing as a strategy to reduce disaster risk (A.E. Collins, 2009). Disasters therefore become a function of the level of development (A.E. Collins, 2009).

The importance to take into consideration local perceptions to overcome an expert-lay divide has also been highlighted in numerous studies, building on the socio-scientific notion of risk as a social construction (Cardona, 2003; Slovic, 1987). This is particularly relevant for development, as it is often the case that development initiatives do not succeed to aid local populations the way they were meant to, and, as a consequence of this, there has been a call for participatory planning for disaster risk reduction to involve local communities in the design and implementation of disaster risk management strategies (Abarquez & Murshed, 2004; Pelling, 2007; UNISDR, 2015b).

The links between development and disasters become particularly evident in the post-disaster recovery phase, when rehabilitation and reconstruction efforts must go hand in hand with development initiatives.

The Sendai Framework, like other reference international agreements, has emphasised the concept of *build back better*, as also reflected in one of its four priorities for action: priority for action 4 on 'Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction' (UNISDR, 2015b).

The concept of *build back better* has emerged in the disaster risk management literature since the 1990's and has then been adopted by practitioners and policy-makers worldwide, e.g., in the aftermath of the 2004 tsunami (Kennedy, Ashmore, Babister, & Kelman, 2008; Lyons, 2009; Mannakkara & Wilkinson, 2013). It relies on the principle of using post-disaster recovery as an opportunity to adopt a holistic approach towards rebuilding that comprehensively addresses the socio-economic, infrastructural and environmental conditions of affected communities to create a safer environment that will enhance people's ability to cope with future hazards (Mannakkara & Wilkinson, 2013).

Recovery and reconstruction, thus, are seen are opportunities for transformation to avoid rebuilding pre-existing vulnerabilities and reduce residual risks. In this sense, development and disaster risk reduction become mutually intertwined.

## 2.4 Post-disaster recovery

Despite being the subject of a growing number of literature (Amin & Goldstein, 2008; Becker, Saunders, Wright, & Johnston, 2011; Berke, Kartez, & Wenger, 1993; Brown et al., 2008; C.G. Burton, 2014; Chhotray & Few, 2012; Chhotray, Hill, Biswal, & Behera, 2013; Abhijeet Deshmukh & Hastak, 2009; Ingram, Franco, Rio, & Khazai, 2006; Krishnan, 2011; Mannakkara & Wilkinson, 2013; Quarantelli, 1989, 1999; Wold, 2006), post-disaster recovery continues to be poorly researched (Ryan & Wortley, 2016).

While the concept has been defined in different ways across different disciplines, ranging from civil engineering to social and human sciences (Aldrich, 2011; Becker et al., 2011; Berke et al., 1993; C.G. Burton, 2014; Chamlee-Wright & Storr, 2011; Abhijeet Deshmukh & Hastak, 2009; Ingram et al., 2006; Mannakkara & Wilkinson, 2013; Nakagawa & Shaw, 2004), there is little consensus on what recovery means and the interpretation of the concept remains clouded (Ingram et al., 2006; Quarantelli, 1989, 1999).

The conceptual shift from reactive disaster management focused on response and short-term recovery to pre-disaster action founded on prevention and preparedness has highlighted the need to plan for long-term recovery, which had been neglected until recently (Garnett & Moore, 2010).

Governments and international organisations worldwide are placing great emphasis on fostering the resilience of communities to natural hazards, including by promoting 'build back better' approaches after a disaster strikes. As McGuire (2005) puts it in the title of one of his articles, 'Global disaster paves way for global thinking' and, with disaster risk reduction having emerged as a global challenge, the Sendai Framework for Disaster Risk Reduction 2015-2030 has recognised that recovery needs to be planned for ahead of a disaster and can be an opportunity to build back better (UNISDR, 2015b).

The ability to assess recovery is increasingly being identified as a key step towards disaster risk reduction by practitioners and policy makers worldwide, who acknowledge that, in order to successfully and strategically plan for risk reduction, it becomes essential to understand, identify and assess all sets of conditions that contribute to recovery and establish baselines against which to measure progress. This is because various environmental, built-environment, and social factors will operate and interact differentially across different disaster and development contexts. In particular, it is now widely accepted that social capital plays an essential role in driving differential recovery and, thus, recovery studies should not be limited to physical assets (Aldrich, 2011; Chamlee-Wright & Storr, 2011; Nakagawa & Shaw, 2004).

Therefore, despite limited consensus on the theoretical interpretation of recovery from natural hazards, several efforts have been made to translate this descriptive concept into policy and practice, first in the academia, then in communities of practitioners and finally on the international agenda.

In particular, some studies have attempted to assess post-disaster recovery using pre-defined sets of parameters, often limited to a specific sector or sphere of intervention (cf. housing, agriculture, mental health, etc.). However, what constitutes good practices for recovery continues to be highly debated in academic circles and elsewhere (Quarantelli, 1989, 1999; Weichselgartner & Kelman, 2015).

This conflictual relationship has been seen by some as an opportunity for post-disaster recovery research to bring together theory and practice by contributing to gather evidence of what effective recovery is in practical terms to inform its theoretical delineation (Kelman et al., 2015; Quarantelli, 1989, 1999; Weichselgartner & Kelman, 2015).

In an effort to develop a common terminology, which is considered as the international reference for the purpose of this thesis, the United Nations' open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction has defined recovery as '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' (United Nations, 2016c, p. 21).

However, what qualifies as “restoring or improving” livelihoods, health, assets, systems and activities to avoid or reduce future disaster risk and build back “better” remains an open question (Kennedy et al., 2008; Nakagawa & Shaw, 2004; Quarantelli, 1999).

A core issue nested in the definition of recovery itself lies in defining the borders and/or links between recovery on one side and response, reconstruction, rehabilitation and restoration on the other side, with many of these words being commonly used interchangeably (Quarantelli, 1999).

The need to foster community resilience to natural hazards to expedite recovery has also been widely covered and recovery by building back better has been acknowledged as an essential feature of disaster resilience to implement the global disaster risk reduction agenda on the ground, as highlighted in UNISDR’s New Ten Essentials for Making Cities Resilient as part of the Making Cities Resilient Campaign (UNISDR, 2017; United Nations Office for Disaster Risk Reduction (UNISDR), 2017).

Similarly to disaster resilience research, though, the nexus between post-disaster desirable conditions and the pre-disaster situation is yet to be established and may vary depending by context and social groups (Quarantelli, 1999). In the disaster resilience literature, several authors have questioned whether resilience should even be a desirable attribute, especially when looking, for instance, at communities facing chronic challenges (Klein, Nicholls, & Thomalla, 2004; Weichselgartner & Kelman, 2015). This criticism pertaining to what has been termed ‘the dark side of resilience’, refers to the possibility that a resilient system may be one that favours the ‘persistence of a negative system’, whose own resilience may be at risk (Mitchell & Harris, 2012, p. 5).

Similarly, there is a lack of evidence of which desirable attributes should be sought as outputs of the recovery process and these may as well differ from pre-impact conditions (Quarantelli, 1999; Ryan & Wortley, 2016). This leads to the question of how to measure success or failure of recovery strategies (Quarantelli, 1999; Ryan & Wortley, 2016).

A few studies have attempted to identify (un)success factors, either quantitatively or qualitatively, often limited to a specific field of application (Berke et al., 1993; C.G. Burton, 2014; W. Chow, 2000; W. S. Chow & Ha, 2009; Garnett & Moore, 2010; Marshall & Schrank, 2014; Miles & Chang, 2003; Ryan & Wortley, 2016; Silverman, 2006). These include the development of frameworks for post-disaster recovery assessment at the city scale (Miles & Chang, 2003), at the community level (C.G. Burton, 2014), for specific activities such as small businesses (Marshall & Schrank, 2014) and at the individual’s level (Abramson, Stehling-Ariza, Park, Walsh, & Culp, 2010), which also highlights the issue of scale (Quarantelli, 1999). These frameworks for post-disaster recovery assessment draw from some of the most widely used frameworks for development applications, such as the Sustainable Livelihoods Framework, which looks at how different types of livelihood assets or capitals (human, social, natural, physical and financial) influence development outcomes (DFID, 1999).

Most of these frameworks, however, have been developed locally, for contextualised applications (Plyer & Ortiz, 2011; Ryan & Wortley, 2016), and limited evidence of long-term recovery from past disasters exists (Garnett & Moore, 2010). In particular, a generally insufficient amount of evaluation evidence produced has been reported as a common issue (Ryan & Wortley, 2016).

Furthermore, how to evaluate the cascading effects of interlinked hazards and how to assess recovery in the face of subsequent disasters has also been questioned in literature (Quarantelli, 1999). While there continues to be disagreement over the conceptualisation of recovery and its translation to practice and policy, there is general consensus that this is largely due to the lack of evidence of what successful recovery looks like and an understanding of how different communities have recovered differently in the face of natural hazards could help shed light on the connotations of recovery and the broad socio-economic, infrastructural and environmental factors that have an influence on it (Ryan & Wortley, 2016).

Evidence of recovery can be gathered from different sources, including official data from governments, post-disaster needs assessments, government inquiries, operational reviews and other types of evaluations (Ryan & Wortley, 2016).

The development of metrics for post-disaster recovery assessment has drawn from socio-economic variables measured from national census and other sources (Burton, 2014; Plyer & Ortiz, 2011; Ryan & Wortley, 2016), but recent advancements in satellite remote sensing techniques have also paved the way for new applications to evaluate recovery from past disaster events by understanding spatial changes using satellite imagery (Brown et al., 2015, 2008; Dash & Ogutu, 2016).

The use of these sources of data for disaster applications is discussed in the next section.

## 2.5 The use of census and satellite remote sensing data to understand changes in development and disasters

Socio-economic data derived from national census have been largely used to understand societal characteristics that may have an impact on an individual's or a community's ability to cope with natural hazards (Norris, 2006). These data have been predominantly used in the context of data-rich, developed countries and less frequently in the developing world for issues concerning data availability (Devarajan, 2013; Norris, 2006).

Many studies have been conducted to investigate socio-economic conditions and their relation with disasters, using census data (C.G. Burton, 2014; DFID, 1999; Flanagan, Gregory, Hallisey, & Al., 2011; Norris, 2006). Most frameworks for vulnerability and resilience assessment have also been built on sets of indicators, which widely rely on census for input data (Bruneau et al., 2003; C.G. Burton, 2014; Chambers & Conway, 1991; Cutter et al., 2008; DFID, 1999; Peacock et al., 2010; Sherrieb, Norris, & Galea, 2010; Tierney & Bruneau, 2007; UNISDR, 2017; United Nations Office for Disaster Risk Reduction (UNISDR), 2017).

Despite the controversy around the theory of resilience and vulnerability, the ability to measure vulnerability and resilience have been increasingly identified as a key step towards disaster risk reduction based on the assumption that, in order to successfully build community resilience and/or reduce vulnerability to natural hazards, it becomes essential to understand, identify and assess all sets of conditions that contribute to them (UNISDR, 2015b; United Nations Office for Disaster Risk Reduction (UNISDR), 2017).

Similarly, the need to measure recovery has emerged as a key issue for the definition of successful recovery strategies. As a result, several international initiatives have been conducted to develop guidelines for measuring these concepts and move forward towards their operationalisation, largely making use of socio-economic indicators derived from census (UNISDR, 2017).

The use of quantitative metrics to develop recovery, resilience or vulnerability assessments that compile a series of indicators into a combined index has been questioned for not properly addressing all the factors that may influence resilience and for limiting the analysis to quantifiable parameters and to data availability (Dauphiné & Provitolo, 2007; Weichselgartner & Kelman, 2015).

It has been pointed that not all aspects of recovery, resilience or vulnerability can be captured by quantification and that a broad range of qualitative factors, including perceptions of risk, must be accounted for (Kelman et al., 2015).

Moreover, it has been noted that many indicators typically used in frameworks for disaster recovery, resilience or vulnerability assessment are indicators of development, highlighting the nexus between disaster risk reduction and development and questioning the peculiar characterisation of resilience/vulnerability: while it is widely accepted that development and disaster risk are closely related, there is a lack of empirical evidence of these interactions (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013; Kelman et al., 2015; Mochizuki, Mechler, Hochrainer-Stigler, Keating, & Williges, 2014b; Weichselgartner & Kelman, 2015).

While the use of socio-economic data from census or other types of population surveys can provide key information, relying solely on them presents many limitations, for example the lack of coverage in between enumeration periods (Watmough, Atkinson, & Hutton, 2013a, 2013b). To fill this gap, the use of mixed methods has been recognised as a valid approach to overcome the limitations of single methodological approaches (Kelman et al., 2015; Weichselgartner & Kelman, 2015).

Since the first appearance of satellite images in the 1970's, remote sensing has opened new frontiers for data acquisition, with a mass of new data becoming available for research and operational purposes (Dash & Ogutu, 2016; Tronin, 2010).

Remote sensing imagery is increasingly being used to understand spatial and temporal changes for both development and disaster applications (Amin & Goldstein, 2008; Archer & Clarke, 2012; Avtar et al., 2020; CEOS, 2002; Dash & Ogutu, 2016; Dash, Steinle, Singh, & Bähr, 2004; Gahler, 2016; Joyce, Belliss, Samsonov, McNeill, & Glassey, 2009).

Earth observation provides the opportunity to address large geographical areas at once and to perform systematic and repeatable analyses (Archer & Clarke, 2012). For this reason, satellite remote sensing has huge potential for sustainable development applications, including monitoring of the Sustainable Development Goals (Hargreaves & Watmough, 2021; Sustainable Development Solutions Network, 2015). Increased data availability made possible through satellite information has also paved the way for numerous applications to address the various phases of the disaster risk management cycle, including in geographic context where data derived from other sources may be limited.

A review by Avtar et al. (2020) of the literature published between 1 January 2001 and 15 May 2020 related to the use of remote sensing for sustainable development applications found that reviewed studies focused on the following categories: population, environmental assessment, biodiversity, quality of life, groundwater, transportation, landslide mitigation and management, mineral resources, and flood hazard forecasting and assessment. Findings from the review show that disaster risk management is a researched sub-set of sustainable development, with most papers focusing on applications of satellite remote sensing for flood forecasting and landslide mitigation/management. Out of all articles reviewed, none covered post-disaster recovery.

Satellite remote sensing, however, has huge potential for application across the whole disaster risk management cycle.

An overview of the main type of applications by hazard type and phase is provided in Table 2.1 below.

Table 2.1: Areas with potential for application of remote sensing techniques mapped by type of hazard and phase of the disaster risk management cycle (Lewis, 2009)

| **Type of Hazard** | **Mitigation** | **Preparedness** | **Response** | **Recovery** |
|---|---|---|---|---|
| Cyclone | Risk modelling; vulnerability analysis. | Early warning; long-range climate modelling. | Identifying escape routes; crisis mapping; impact assessment; cyclone monitoring; storm surge predictions. | Damage assessment; spatial planning. |
| Drought | Risk modelling; vulnerability analysis; land and water management planning. | Weather forecasting; vegetation monitoring; crop water requirement mapping; early warning. | Monitoring vegetation; damage assessment. | Informing drought mitigation. |
| Earthquake | Building stock assessment; hazard mapping. | Measuring strain accumulation. | Planning routes for search and rescue; damage assessment; evacuation planning; deformation mapping. | Damage assessment; identifying sites for rehabilitation. |
| Fire | Mapping fire-prone areas; monitoring fuel load; risk modelling. | Fire detection; predicting spread/direction of fire; early warning. | Coordinating fire fighting efforts. | Damage assessment. |
| Flood | Mapping flood-prone areas; delineating flood-plains; land-use mapping. | Flood detection; early warning; rainfall mapping. | Flood mapping; evacuation planning; damage assessment. | Damage assessment; spatial planning. |
| Landslide | Risk modelling; hazard mapping; digital elevation models. | Monitoring rainfall and slope stability. | Mapping affected areas; | Damage assessment; spatial planning; suggesting management practices. |
| Volcano | Risk modelling; hazard mapping; digital elevation models. | Emissions monitoring; thermal alerts. | Mapping lava flows; evacuation planning. | Damage assessment; spatial planning. |

Satellite remote sensing is classified into three types with respect to the wavelength regions: a) visible and reflective infrared, b) thermal infrared and c) microwave. The types of satellites and sensors also vary by spatial scale and frequency of observations. Geostationary satellites, for instance, are positioned at a high altitude (35,800 km ca.) and provide data for larger areas at high frequency (every 15 minutes) but with a coarse resolution (Gahler, 2016; Joyce et al., 2009). They can be used for monitoring weather patterns, volcanic ashes, etc. (Joyce et al., 2009). Polar-orbiting satellites, instead, provide high resolution data and, thus, a great degree of detail, but with low frequency (every few days) (Gahler, 2016; Joyce et al., 2009). They have been used, for example, to monitor infrastructure changes and damages, as well as debris removal (Joyce et al., 2009).

A detailed overview of the type of application of different wavebands is provided in Table 2.2.

Table 2.2: Satellite remote sensing applications by wavelength, waveband and sensors

| **Wavelength** | **Waveband** | **Applications** | **Sample sensors** |
|---|---|---|---|
| Visible | 0.4-0.7mm | Vegetation mapping | SPOT; Landsat TM |
| | | Building stock assessment | AVHRR; MODIS; IKONOS |
| | | Population density | IKONOS; MODIS |
| | | Digital elevation model | ASTER; PRISM |
| Near infrared | 0.7-1.0mm | Vegetation mapping | SPOT; Landsat TM; AVHRR; MODIS |
| | | Flood mapping | MODIS |
| Shortwave infrared | 0.7-3.0mm | Water vapour | AIRS |
| Thermal infrared | 3.0-14mm | Active fire detection | MODIS |
| | | Burn scar mapping | MODIS |
| | | Hotspots | MODIS; AVHRR |
| | | Volcanic activity | Hyperion |
| Microwave (radar) | 0.1-100cm | Earth deformation and ground movement | Radarsat SAR; PALSAR |
| | | Rainfall | Meteosat; Microwave Imager (aboard TRMM) |
| | | River discharge and volume | AMSR-E |
| | | Flood mapping and forecasting | AMSR-E |
| | | Surface winds | QuikScat radar |
| | | 3D storm structure | Precipitation radar (aboard TRMM) |

Satellite data are especially of interest when assessing post-disaster recovery (Brown et al., 2015, 2008; Dash et al., 2004; Ghaffarian, Kerle, & Filatova, 2018). Among all the different phases of the disaster risk management cycle, post-disaster recovery represents an ideal one for addressing long-term risk reduction (Becker et al., 2011). Remote sensing applications for recovery, however, appear to be the least developed, despite the recognition that there is great potential for the remote sensing community to work on time series analysis of remotely sensed data to identify disaster recovery indicators that can be measured and monitored from earth observation (Ghaffarian et al., 2018; Joyce et al., 2009).

Several studies have attempted to understand what visible recovery characteristics could be in a certain area over a pre-determined period of time following a disaster using change detection techniques, with the objective to measure and monitor these at key intervals in time to quantify changes (Archer & Clarke, 2012; Brown et al., 2015, 2008). Images can be classified to identify post-disaster recovery indicators and understand which ones have contributed to a quicker or slower recovery (Archer & Clarke, 2012; Brown et al., 2008). The status of recovery in any given location can, thus, be monitored over time and the differential recovery across a sample of places affected by the same event can be investigated (Archer & Clarke, 2012). Features that have been used to provide evidence of recovery include changes in settlement distribution and density, building footmarks, land use, vegetation and infrastructure. Evidence of recovery from other sources can also help in identifying significant interval of times over which to acquire imagery to look for changes (Brown et al., 2008). Similarly, the acquisition of satellite images following multiple disasters caused by natural hazards can help in monitoring and assessing post-disaster recovery (Brown et al., 2008; Ghaffarian et al., 2018).

The analysis of remote sensing imagery could additionally contribute to analysing alternative recovery strategies and identifying the most successful in terms of quicker recovery rates (Joyce et al., 2009). Finally, this type of information can help in identifying areas that are recovering in a slower manner and , therefore, will present increased residual risks until complete recovery (Joyce et al., 2009).

Joyce et al. (2009) have mapped the type of information that could be estimated using remote sensing data (Table 2.3).

Table 2.3: Data requirements, sensors and applications of remote sensing techniques depending on the type of information sought

| Type of information | Data required | Sample sensors | Applications |
|---|---|---|---|
| Rate of recovery - e.g., debris removal, vegetation regrowth, reconstruction) | Moderate to very high resolution imagery in a continuous time series | Aerial photography, Quickbird, Worldview, Ikonos | Compare the effectiveness of different recovery strategies; Determine if aid funding is being used appropriately; Wildlife habitat recovery (e.g., after fire); Identify "residual risk" - areas not recovered that are more vulnerable to future events |
| Infrastructure and facilities locations | Very high resolution imagery | Aerial photography, Quickbird, Worldview, Ikonos | Create new baseline maps |
| Revised DEM | InSAR, LiDAR | -1/2, ENVISAT ASAR, ALOS PALSAR | Necessary after large earthquake or volcanic eruption if the local and regional elevation changes |
| Status Quo | Very high resolution imagery | Aerial photography, Quickbird, Worldview, Ikonos | Plan areas for funding allocation |

Overall, remote sensing has been widely applied in the context of natural hazards (Deichmann, Ehrlich, Small, & Zeug, 2011; Geiß & Taubenböck, 2013; Showalter, 2001; Tronin, 2010). These studies have focused on different natural hazards as well as on human responses to disasters (Showalter, 2001). Specific applications of remote sensing to disaster risk management include risk assessments, landslide detection, floodplain and inundation mapping, damage assessment, and land use mapping for spatial planning purposes (Geiß & Taubenböck, 2013; Showalter, 2001; Tronin, 2010).

Practical examples of remote sensing applications for post-disaster recovery assessment include, for example, the monitoring of post-Katrina recovery in New Orleans (Archer & Clarke, 2012; C.G. Burton, 2014; Flanagan, Gregory, Hallisey, Heitgerd, & Lewis, 2011) or post-Nargis recovery in Myanmar (Matsuda, 2012; Stone, 2009). These, however, represent only a minority of satellite remote sensing studies, with the large majority being limited in time and primarily focusing on direct comparison between pre- and immediately post-disaster images to understand short-term impact.

Remote sensing has been often applied for monitoring the use of natural resources, and earth observations have been a particularly powerful tool when applied to agriculture (Atzberger, 2013; Dash & Ogutu, 2016). Typical applications for agriculture include land cover mapping, biomass and yield estimation, irrigation monitoring and planning, stress detection, pest control, soil moisture/toxicity estimation and drought monitoring, water availability, wildlife inventory, etc., where remote sensing can be used both for operational purposes and for strategic planning (Atzberger, 2013; Dash & Ogutu, 2016).

Vegetation phenology has been used to map land cover and land use changes. In particular, broad land use types and vegetation cover can be derived from the use of vegetation indices, among which the Normalised Difference Vegetation Index (NDVI) is the most used in remote sensing (Atzberger, 2013; J. M. A. Duncan, Dash, & Atkinson, 2014). A review by Avtar et al. (2020) compiled 47 major spectral indices developed using remote sensing data for applications in sustainable development found to be used in literature between 1966 and today. These indices were found to focus mainly on three areas: vegetation, water and soil. However, the large majority of them, i.e., 35 out 47, were vegetation indices, ranging from NDVI to the Leaf Area Index (LAI), Enhanced Vegetation Index (EVI), Ratio Vegetation Index (RVI), Difference Vegetation Index (DVI), Perpendicular Vegetation Index (PVI), Soil-Adjusted Vegetation Index (SAVI), etc. This type of information can significantly contribute to evaluating post-disaster recovery of social and environmental systems. Monitoring change in the face of natural hazards is key to understanding recovery mechanisms to inform action and the availability of remote sensing data has significantly contributed to the development of new techniques for damage assessment and recovery planning.

With the advent of satellite remote sensing and the consequent increase in data availability, some studies have combined socio-economic indicators derived from census variables with remote sensing parameters to increase data coverage for environmental applications (Cai & Sharma, 2010; Chen, 2002; de Espindola, de Aguiar, Pebesma, Câmara, & Fonseca, 2012; Frolking et al., 2002; G. Li & Weng, 2007; Martinuzzi, Gould, & Ramos González, 2007; Watmough et al., 2013a; Watmough, Atkinson, & Hutton, 2013c).

A growing body of literature, in particular, has explored the potential of satellite remote sensing data to be used as proxies for social data, including for the prediction of socio-economic outcomes (Watmough, Atkinson & Hutton, 2013a). They draw from the well-established evidence that the poorest populations worldwide extensively rely on natural resources for their livelihoods, while also being concentrated in socially and ecologically fragile areas (Watmough, Atkinson, Saikia, & Hutton, 2016; Sen, 2003). As a result, competition over natural resources and the pressure exercised on them by population growth are impediments to sustainable human development, with complex feedback loops between population and environmental change (Watmough, Atkinson, Saikia, & Hutton, 2016).

These studies have found significant relationships between socio-economic variables from census (e.g., age distribution, female literacy, household assets, etc.) and physical variables from satellite remote sensing (e.g., land cover, vegetation indices, impervious surfaces, etc.) (Watmough, Atkinson & Hutton, 2013a). They suggest that satellite remote sensing could be used to monitor and predict population change and social welfare. This has opened new horizons for studying the relationship between population, poverty and local environmental conditions (Watmough, Atkinson, Saikia, & Hutton, 2016; Watmough, Atkinson & Hutton, 2013a). These applications are particularly beneficial in data-poor contexts and to overcome some of the limitations of relying on information from census and other population surveys with limited data points (Watmough, Atkinson & Hutton, 2013a, 2013b).

These studies have predominantly focused on understanding land cover changes and are mostly oriented to applications in the field of agriculture, rural poverty or urban planning, there appears to be a lack of studies combining these methods for disaster applications and, in particular, for investigating differential spatial post-disaster recovery.

A review by Heargreaves and Watmough (2021) of satellites, sensors and data products most routinely used for the application of earth observation data to rural sustainable development found that the Normalised Difference Vegetation Index (NDVI) was the most used data product, alongside land use, land cover and Night-Time Lights (NTL).

Specifically, they found that NDVI was most used as a proxy for crop cycles and to measure agricultural productivity, which is often associated with rural poverty as higher crop yields can generate greater income. This is in line with research on agricultural productivity, which has demonstrated the role of NDVI in assessing crop health, including to improve crop yield, and for disaster risk reduction (Nhamo et al., 2020). Out of 47 major spectral indices compiled from literature, Avtar et al. (2020) found that NDVI was found to perform particularly well for sustainable development applications despite having been developed a long time ago when the sensor radiometric resolution and spatial resolution were lower than they are today, which was found to be in contrast with the performance of other reviewed vegetation, water and soil indices. According to Huang et al. (2021), NDVI is the most popular index used for vegetation assessment, with research demonstrating its effectiveness to differentiate agricultural fields and to estimate different vegetation properties, including plant productivity or crop yield (Nhamo et al., 2020; van Klompenburg, Kassahun & Catal, 2020). A systematic review by Mohan and Venkatesen (2020) also concluded that NDVI is the most commonly used vegetation index in crop yield prediction models based on earth observation.

NTL, on the other hand, is mainly used in urban areas as a proxy for gross domestic product (GDP); its application in the developing world, however, is limited due to lower access to electricity and prevalence of public lighting (Doll et al., 2006; Heargreaves and Watmough), with an estimated 1.5 billion people undetectable by NTL data (Doll and Pachauri 2010).

In mapping the requirements for estimating socio-economic proxies from earth observation data, Heargreaves and Watmough (2021) found that high spatial resolution satellite imagery is required to proxy rural poverty at the household level; a combination of information on roads, schools and markets that can be extracted from open public street mapping databases together with high spatial resolution satellite imagery is required to do so at the community level; and agricultural productivity, access to large towns and cities and information on natural hazards is effective at greater scale, with most approaches developed so far proxying only one socio-economic metric at a time.

## 2.6 Disasters and development in the Kendrapara District of Odisha, India

The Kendrapara District of Odisha is located on the East coast of India. An overview of the physical and socio-economic characteristics of the area is provided in the following sections. Four key areas relevant to the proposed research are addressed: (i) exposure to natural hazards; (ii) economic development; (iii) poverty issues; and (iv) government policies for poverty alleviation.

### 2.6.1 Exposure to natural hazards

The State of Odisha is exposed to a broad range of natural hazards, of which tropical cyclones have been the most destructive (Chittibabu, Dube, Macnabb, et al., 2004).

Tropical cyclones are natural phenomena originating over tropical oceans under defined climatological conditions, which include warm ocean surface temperatures, low vertical wind shears and high large-scale relative vorticity of the air flow (Emanuel, 2003, 2005; Gray, 1968; Knutson et al., 2010; WMO, 2006). On a global scale, tropical cyclones already cause massive economic damages every year and, together with floods, present the highest associated mortality risk amongst natural hazards (Emanuel, 2003). Their future trends in terms of intensity and frequency have been the subject of extensive debate in recent years.

While no broad consensus on the topic has been reached so far due to considerable uncertainties in climate projections, with intensity arguably increasing under climate change and frequency likely to either decrease or remain unchanged, it is widely accepted that precipitation patterns in tropical regions will become more extreme, and flooding from tropical cyclones will increase as a result of sea level rise (Emanuel, 2005; Knutson et al., 2010; Luther et al., 2017; Wong et al., 2014; Woodruff et al., 2013).

Furthermore, exposure to these natural phenomena is rapidly growing worldwide as coastal urbanisation driven by greater economic productivity and comparative advantages is leading to higher concentrations of population in areas at risk (UNISDR, 2013, 2015a).

It is interesting to notice, for instance, that, while the overall population growth was 87% in the years 1970-2010, the population in cyclone-prone coastlines over the same period grew by 192%, with most of this increase taking place in Asia (UNISDR, 2013). This demographic growth and the rising value of properties and infrastructure in exposed locations have led and will lead to a significant increase in the economic losses caused by tropical cyclones in recent years (Knutson et al., 2010; Mendelsohn, Emanuel, Chonabayashi, & Bakkensen, 2012; Woodruff et al., 2013).

However, economic development also drives improved disaster management capacities and can consequently ultimately contribute to reducing vulnerability despite greater exposure (Kahn, 2005).

Exposure to tropical cyclones is particularly significant in deltaic regions. In fact, deltas are low-lying coastal landforms which combine complex natural and human systems and, as such, on the one side are sensitive to climatic stresses from both rivers upstream and oceans downstream, with sea level rise predicted to have a high impact on them, and, on the other side, are affected by anthropogenic activities (e.g., groundwater, oil and gas extraction) which are responsible for enhanced land subsidence (Wong et al., 2014; Woodruff et al., 2013). Changes in sea level due to climate change are therefore expected to further amplify flooding from tropical cyclones if no counter measures are taken to alleviate negative consequences (Woodruff et al., 2013).

However, despite disaster risk, deltaic regions have a huge economic potential and attract large investments due to their high profitability linked to extraction and port activities, agriculture, and tourism (UNISDR, 2013), and it consequently becomes essential to adopt a holistic approach to tropical cyclone risk management that accounts for changes in land subsidence and sediment supply induced by human activities, particularly in urban centres and international ports (Woodruff et al., 2013).

The Indian state of Odisha is highly prone to tropical cyclones, which severely hit its coast numerous times in the past years (Chittibabu, Dube, Macnabb, et al., 2004). The cyclone classification by maximum sustained wind speed and pressure deficit adopted by the India Meteorological Department (IMD) is provided in Figure 2.2.

According to IMD, the most intense recorded cyclonic storm over the North Indian Ocean is the 1999 Odisha Super Cyclonic Storm, which made landfall on the Indian Eastern coast near Paradip on 29th October 1999, with an estimated sustained maximum surface wind speed of 140 knots at the time of landfall and a lowest estimated central pressure of 912 hPa (Kalsi, 2006).

The second most intense cyclone on India’s coasts is cyclone Phailin, which crossed Odisha and its neighbouring state of Andra Pradesh near Gopalpur, Odisha on 12th October 2013 with an estimated sustained maximum surface wind speed of 115 knots and an estimated central pressure of 940 hPa (IMD, 2013).

On 12th October 2014, cyclone HudHud made landfall in east-central India near Visakhapatnam, Andra Pradesh with maximum sustained winds of 110 knots. It may be useful to remind that the above mentioned maximum sustained wind speed is calculated by IMD as the system’s highest value of surface wind averaged over a three-minute period, observed or estimated at a height of 10 m in an unobstructed environment.

| System | Pressure deficient hPa | Associated wind speed Knots (Kmph) |
|---|---|---|
| Low pressure area | 1.0 | <17(<32) |
| Depression | 1.0- 3.0 | 17-27 (32–50) |
| Deep Depression | 3.0 - 4.5 | 28-33 (51–59) |
| Cyclonic Storm | 4.5- 8.5 | 34-47 (60-90) |
| Severe Cyclonic Storm (SCS) | 8.5-15.5 | 48-63 (90-119) |
| Very Severe Cyclonic Storm | 15.5-65.6 | 64-119 (119-220) |
| Super Cyclonic Storm | >65.6 | >119(>220) |

Figure 2.2: Official classification of tropical cyclones by the IMD, with related pressure deficit and associated wind speed

In terms of losses, the 1999 super cyclone caused 9,893 fatalities and estimated economic damages for 2.5 billion dollars (Kalsi, 2006). Fourteen years later, cyclone Phailin led to 38 reported casualties in the state of Odisha, of which 21 caused by the cyclone itself and 17 by consequent flooding, and 1 reported casualty in Andra Pradesh (IMD, 2013). During the same event, the affected population was 12,396,065, and 1,154,725 people in Odisha and 134,426 in Andra Pradesh were evacuated; affected farmland was estimated at 668,268 ha in Odisha and 6,192 in Andra Pradesh (IMD, 2013). In 2014, cyclone HudHud caused the loss of 46 human lives, while 135,262 people were evacuated by the authorities following advance warnings released by IMD; 2,370,000 ha of farmland were heavily damaged, according to the Times of India.

Records, therefore, suggest that successful early warning and evacuation systems led to reduced human losses. However, economic damages still severely impact affected regions, causing loss of livelihoods.

While tropical cyclones remain the most devastating natural hazard in Odisha, the State is also exposed to floods, droughts and heat waves. The Kendrapara District of Odisha, in particular, is not significantly exposed to droughts, which predominantly affect the western districts of Odisha; however, it has suffered from recurrent floods in 1980, 1982, 2001, 2003, 2006, July 2007 (storm surge and saline inundation), September 2008 and 2009 (NIDM, 2014). An unprecedented heatwave also affected the State of Odisha in 1998 (NIDM, 2014).

### 2.6.2 Economic development

Odisha is one of the lowest income states of India and its economy lagged behind national standards in terms of per capita Net State Domestic Product (NSDP) for many years since India's independence, with a per capita NSDP equal to 90% of the country's average in fiscal year 1950-51 decreasing down to about 61% of the country's average in 2002-03 (Government of Odisha, 2011). However, this declining trend has been reversed ever since 2004-05, when the state per capita NSDP began to rise again as shown in Figure 2.3 (Government of Odisha, 2011).

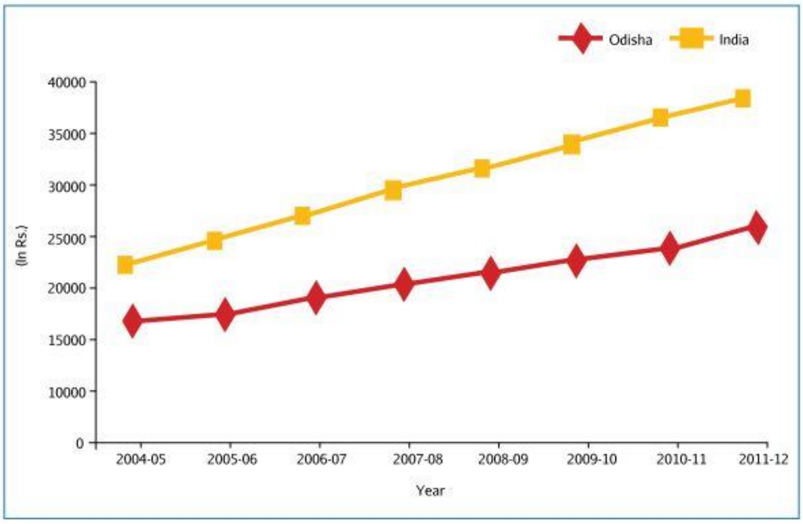


Figure 2.3: Comparison of per capita NSDP trends between Odisha and All India (Government of Odisha, 2011)

Reasons for this positive change have to be sought in the rapid growth of the secondary and tertiary sectors over recent years, which are also reflected in national trends. The service sector, in particular, currently provides the greatest contribution to Odisha's Gross State Domestic Product (GSDP), while agriculture is the sector most exposed to natural hazards such as tropical cyclones, floods and droughts (Government of Odisha, 2011). In 2010-11, the primary sector accounted for 17.59% of the state GSDP, while the secondary and tertiary sectors represented 25.69% and 56.72% respectively of Odisha's GSDP (Government of Odisha, 2011). A comparison of these values with national data is provided in Figure 2.4.

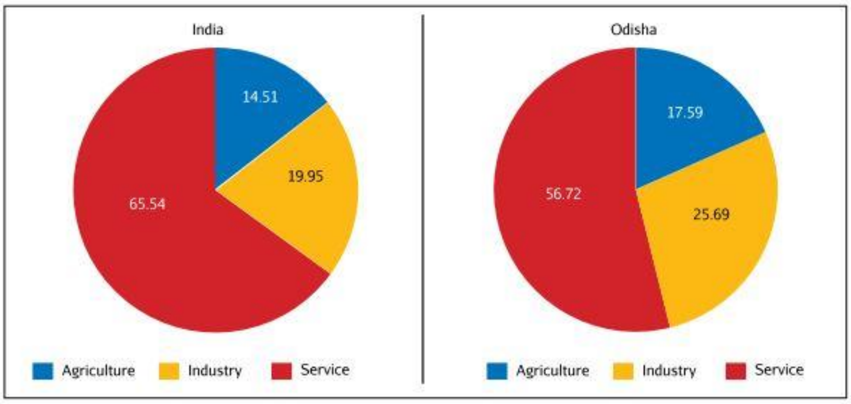


Figure 2.4: Comparison of GDP by economic sector between Odisha and All India (Government of Odisha, 2011)

As per national census data, the labour force in the state of Odisha accounts for 38.79% of the total population, in line with the national datum of 39.1% (Government of Odisha, 2011). The share of workers employed in the agricultural sector (cultivators and agricultural workers) out of the total working population was 58% in 2001, significantly less than the 1991 datum of 73% (Government of Odisha, 2011). Agriculture is therefore the primary source of livelihood for the majority of the state population, despite contributing to less than 20% of GSDP.

Rice constitutes about 90% of the total production of food grains, with its productivity being slowly increasing while still remaining lower than the national average (Government of Odisha, 2011).

The boost of the industry and service sectors over the past decade, however, is contributing to a differentiation of revenue sources; Odisha already hosts several plants for aluminum, steel and iron production, and is the target of more investments in the field (cf. Vedant, Jindal, Posco).

### 2.6.3 Poverty issues

As previously mentioned, Odisha is one of the lowest income states of India and poverty issues are of serious concern. While the poverty ratio has declined in the state in the past decades, the rural-urban poverty gap remains greater than the national average and rural poverty is still reportedly higher than urban poverty (Government of Odisha, 2011; Government of Orissa, 2004).

The overall spatial distribution of poverty is not uniform, but rather characterised by significant regional differences (Figure 2.4). In particular, coastal areas have the lowest incidence of poverty, while the largest poverty ratio is found in the southern regions (Government of Odisha, 2011; Government of Orissa, 2004).

Reasons for these spatial variations include differences in infrastructure development, in access to employment opportunities (with most industries located on the coast, while southern regions rely primarily on agriculture) and to irrigation (with the south being almost entirely rain-fed), and in the availability of fertilisers.

| Region | Poverty Gap | Squared Poverty Gap |
|---|---|---|
| Coastal | 10.21 | 3.22 |
| Southern | 18.78 | 6.82 |
| Northern | 10.41 | 3.43 |
| Orissa | 11.83 | **3.95** |

Note: Poverty Gap is the percentage difference between the poverty line income/consumption expenditure and the average income/consumption expenditure of the poor. Squared Poverty Gap takes into account expenditure of those below the poverty line.

Source: (i) Government of India (1997), *Sarvekshana*, Vol. XXI, No. 2, 73rd Issue, October–December (NSS 50th Round, 1993–94), Ministry of Statistics, Planning and Programme Implementation, Department of Statistics, New Delhi; (ii) Government of India (2001), *Census of India: Orissa*, Directorate of Census Operations.

Figure 2.4: Poverty gap in Odisha, with its spatial distribution by type of region (Government of Orissa, 2004)

These spatial differences in the incidence of poverty reflect differences in the social dimension of poverty, in terms of ethnic group regional distribution and economic means (Government of Orissa, 2004). In fact, the incidence of poverty among Scheduled Caste (SC) and Scheduled Tribe (ST) population in the southern and northern regions is very high, with 88.56 % of the state ST population and 46.23% of the state SC population residing in these areas (Government of Orissa, 2004).

### 2.6.4 Safety nets

In light of these poverty issues, strategies for poverty alleviation and food security have been the focus of significant public interventions in India.

The Public Distribution System (PDS) is a governmental scheme, which aims to facilitate the supply of food grains to low-income citizens at a subsidised price (Planning Commission; Government of India, 2002). As such, it is an alternative approach to cash transfers and microfinance programmes, and it addresses the two main conditions necessary to ensure food security, i.e., accessibility and affordability.

In its most recent form, defined by the 2013 National Food Security Act, the system targets below the poverty line households (namely, Antyodaya Anna Yojana households), which can claim a monthly entitlement of 35 kilograms of food grains at a reduced price. Other eligible households can claim 5 kilograms of food grains per person per month at subsidised prices of Rs. 3/2/1 per kilogram for rice/wheat/coarse grains. As such, it covers up to 75% of the rural population and up to 50% of the urban population, equivalent to about two-thirds of the population.

The extent of the scheme's coverage has already been reduced from its original form and concerns relating to the need to limit public expenditure on the one side and to ensure proper coverage on the other side have both been raised.

Despite its noble purposes, however, a number of issues affecting its effectiveness have emerged and are the subject of extensive debate. In her study on the utilisation and impact of PDS in Rajasthan, Khera (2011) discussed a broad range of constraints emerging from the scheme. These include low utilisation levels, market diversion, malfunctioning, corruption, and transparency issues.

In particular, it emerged that the use of PDS quotas was low both with regard to number of households actually using it and to the quantities of food grains actually purchased by each household, with only 13% of the sampled population buying their full grain quota.

One of the possible explanations for this behaviour was found to be cash-flow problems, i.e., unavailability of cash to purchase subsidised goods when available in ration shops. Malfunctioning and corruption issues in ration shops were also reported: provided that commissions are low, the research concluded that 'corruption has become a requirement for economic survival for the PDS dealers' as 'the costs of running ration shops end up exceeding revenues generated' (Khera, 2011, p. 1058). Evidence of food grain diversion operated by both PDS dealers and final users was found, with greater extent in north India than south India (Khera, 2011).

Furthermore, the environmental sustainability of PDS is being questioned, as large areas are being dedicated to producing food grains for PDS with significant issues in the use of water for irrigation purposes.

A thorough review of PDS was conducted by Radhakrishna, Subbarao, Indrakant, and Ravi (1997), also in relation to other national poverty alleviation schemes (e.g., self-employment programmes, wage employment programmes and in-kind transfers).

The other major social policy programme which India has put in place at the national level is a large public employment programme, which was introduced under the National Rural Employment Guarantee Act (NREGA) of 2005 and which aims 'to provide for the enhancement of livelihood security of the households in rural areas of the country by providing at least one hundred days of guaranteed wage employment in every financial year to every household whose adult members volunteer to do unskilled manual work' (Government of India, 2005).

The scheme has been conceived to merge strategies for poverty reduction on one side and rural development on the other, by remunerating adults for works of public utility. Similarly, to the PDS, however, NREGA has been the subject of intense scrutiny too and numerous concerns on its efficacy have been raised. These include shortage of dedicated personnel, scheme sabotage due to long administrative and bureaucratic procedures for its implementation, lack of planning, poor quality of works, inappropriate payment rates and absence of audits (Ambasta, Shankar, & Shah, 2008).

In conclusion, significant commitment and financial investments are being made by the government to tackle poverty and to enhance food security. In order for these measures to be effective and to achieve poverty reduction, however, a number of issues concerning coverage, dedicated resources, transparency and corruption have to be further addressed.

## 2.7 Understanding socio-economic, infrastructural and environmental development and post-disaster recovery in the Kendrapara District of Odisha, India

Odisha has experienced positive change in terms of overall social, infrastructural and economic development in recent years. A diversification of the economy and the boost of the second and tertiary sectors has contributed to reversing a negative trend on its NSDP, generating growth and new employment opportunities (Government of Odisha, 2011).

The primary sector, however, remains the main source of livelihoods in the State, where the majority of the working population is still employed in agriculture and rice represents the main agricultural crop in the area (Government of Odisha, 2011). This sector is the most affected by natural hazards and, in particular, by tropical cyclones (Government of Odisha, 2011).

Since the beginning of the XX century, Odisha has faced over 50 cyclonic storms, often with dramatic consequences (Chittibabu, Dube, Macnabb, et al., 2004). While improvements in the State's economy and infrastructure has had a positive impact on the way the society has been able to cope with natural hazards, with a significant contribution to decreasing disaster mortality (UNISDR, 2015a), the population is still highly impacted by disasters of natural origin which continue to cause loss of livelihoods (Government of Odisha, 2011).

The need to invest in disaster risk reduction has been recognised by most nations worldwide, including India, and ratified in major international initiatives such as the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015b).

A common understanding is that, in order to effectively establish policies, programmes and plans for reducing disaster risk at the operational level, it is essential to understand what the baseline conditions are, how communities have evolved over time and in the face of previous disasters and how risk is perceived in a specific context.

While many studies have proposed definitions, methods and metrics to understand post-disaster recovery both in theory and practice, there is still much controversy around measurements. Several studies have attempted to assess disaster recovery in different geographical regions worldwide, often using a set of indicators as a starting point to build composite indices.

These frameworks often consist of a set of variables that have been argued to predominantly refer to development, based on the assumption that development progress enhances community resilience to natural hazards and a community's ability to recover, although clear evidence of the mutual relations between development and post-disaster recovery is still lacking (Barrett & Constas, 2014).

Odisha represents an ideal case study for investigating the association between development and recovery, given its high exposure to natural hazards (Chittibabu, Dube, Macnabb, et al., 2004) and the significant improvements in development conditions it has experienced in recent years (Government of Odisha, 2011; UNISDR, 2015a).

In an attempt to fill the research gaps emerging from literature, this research study therefore looks at investigating how socio-economic, infrastructural and environmental development changes in Odisha have influenced differential recovery at the community level. It uses development as the start line to understand which development changes have occurred in the case study area and how this are perceived by local communities to impact recovery from natural hazards, thus letting local communities explain the interactions between development and recovery based on their experience and understanding.

A data-driven, mixed-method approach was used to gather evidence of past development gains and losses. This consists of: i) a systematic review of the documented losses caused by the 1999 Odisha Super Cyclonic Storm; ii) a statistical analysis of census data to look for objective evidence of change; iii) a satellite remote sensing proxy analysis of recovery rates; and ii) a community-based analysis of community perceptions of socio-economic, infrastructural and environmental development and its relation with speed of recovery, as compared to results from the data analysis.

The relation between socio-economic, infrastructural and environmental development progress and recovery rates is, thus, investigated using a data-oriented approach and has been verified with the help of local communities. Mixed quantitative and qualitative methods were used for the scope and are further detailed in the following chapter.

# Chapter 3: Methodology

## 3.1 Introduction

This chapter presents the overarching conceptual framework, research design and methods used to investigate the interaction between socio-economic, environmental and infrastructural development with post-disaster recovery in Odisha, India.

The theoretical guidance for this thesis comes from the global humanitarian and disaster risk reduction discourses, the disasters and development paradigm and post-disaster recovery frameworks as outlined in Chapter 2.

After discussing the conceptual framework, this chapter outlines the relevance of a multi-disciplinary approach to answering the research questions, the positioning and originality of the research, and the different quantitative and qualitative research methods used.

## 3.2 Conceptual framework

The literature review presented in Chapter 2 shows that evidence of the links between socio-economic, environmental and infrastructural development on one side and post-disaster recovery on the other side remains limited (A.E. Collins, 2018; Mochizuki et al., 2014a) and none exists for the study area.

Previous research has tended to use an arbitrary selection of metrics drawing from development narratives to build recovery indices, without fully investigating the beneficial or counterproductive effects of such relationships (Weichselgartner & Kelman, 2015). These approaches made little attempt to consider local perceptions of development and recovery (ibid.).

Theoretical and methodological limitations have played a role in shaping these research gaps (Mochizuki et al., 2014a). Recognising and overcoming data constraints, in particular, has been identified as one of the key areas for further research (Mochizuki et al., 2014a).

Global leaders are calling for transformational change to face the challenges posed by climate change. This requires evidence of development potentials and their effect on recovery capabilities.

To address these gaps, this thesis aims to look at which socio-economic, environmental and infrastructural development changes have occurred in the study site, which were their attributes, whether these changes reflect faster or slower recovery rates, and whether stakeholders' perceptions of these changes coincide or not with quantitative evidence.

This chapter presents an interdisciplinary methodological framework to answer these questions in the study area. The methodology aims to provide analytical and empirical evidence of the relationship between socio-economic, environmental and infrastructural development with post-disaster recovery rates. In doing so, it also offers the most comprehensive review of losses induced by SC 1999; of the socio-economic, environmental and infrastructural development changes experienced ever since; and of differential recovery rates. To be able to do so, the methodology needs to be suitable to look at the wide range of social and physical factors involved.

### 3.2.1 Positionality

Pragmatism is the philosophical paradigm guiding this research. Creswell (Creswell, 2014) identifies pragmatism as one of four main paradigms or worldviews that influence research, along with postpositivism, constructivism and transformative. When adopting pragmatism, researchers do not commit to anyone's theoretical framework but rather focus on the research problem, using all available approaches to solve it (Creswell, 2014; Rossman & Wilson, 1985).

Pragmatism provides a philosophical framework for mixed methods approaches (Creswell, 2014). Mixed methods approaches can be used to deliberately draw from a wide array of quantitative and qualitative research methods to collect and analyse data, combined in an attempt to best understand the research problem (ibid.).

Mixed methods are especially useful for interdisciplinary research. Interdisciplinary research is widely accepted as a means to combine different perspectives to best capture the complexities of global socio-environmental systems and to address some of the most urgent environmental challenges of our time (Acutt et al., 2000).

This research is multidisciplinary in nature, in that it investigates the interlinkages between different socio-economic, environmental and infrastructural development factors, as well as how they interplay with post-disaster recovery. It, therefore, spans from physical to human geography.

While some of the research questions can be answered using qualitative social research methods, others require an understanding of the natural and built environment that can only be achieved through quantitative spatial and statistical analysis. This provides the rationale for adopting a mixed methods approach.

This research is shaped by pragmatism, translated into the adoption of a data-driven approach and the use of mixed methods. As opposed to hypothesis-driven research, data-driven research has emerged with the advent of big data as a way to harvest the massive quantities of data available to find information that can be turned into knowledge (Kitchin, 2013; Mazzocchi, 2015; Miller & Goodchild, 2015). Data-driven research relies on empiricism by mining data to yield trends, patterns and correlations that are 'born from the data' themselves (Mazzocchi, 2015). As such, it represents a novelty for scientific research, with empirical evidence superseding scientific hypotheses (Mazzocchi, 2015).

The study area is traditionally a data-poor one, with lack of recording and other data constraints having hampered the understanding of response and recovery from SC 1999 so far. However, the wealth of data that has been made available in most recent years has paved the way for reconsidering some of the least studied research topics to fill gaps building on newly available data architecture (Kitchin, 2013; Miller & Goodchild, 2015). A data-driven approach is, therefore, deemed suitable for this context.

### 3.2.2 Study design

Four main types of datasets have been used to achieve the research objectives identified in Chapter 1. The first objective requires a review of available scientific and grey literature to map documented losses caused by SC 1999. The second objective relies upon the statistical analysis of national census data over space and time. The third objective builds on available remotely sensed scenes. Finally, the fourth objective relies on fieldwork conducted in two rounds in the study site. The list of data, methods and outputs for each research objective is provided in Table 3.1.

| ***Research objective*** | | ***Data*** | ***Methods*** | ***Outputs*** |
|---|---|---|---|---|
| I) | Identify socio-economic, environmental and infrastructural losses caused by the 1999 Super Cyclonic Storm in the study site. | Scientific and grey literature | Systematic review | Matrix of losses by type and scale |
| II) | Map socio-economic, environmental and infrastructural development changes through time in the study site and identify hotspots/coldspots. | National census | Statistical analysis | List of socio-economic, environmental and infrastructural development hotspots/coldspots and key associates of change |

| | | | | |
|---|---|---|---|---|
| | | | | |
| III) | Estimate differential post-disaster recovery rates, identify recovery hotspots/coldspots, and compare them with socio-economic, environmental and infrastructural development hotspots/coldspots | Satellite images, landcover | Remote sensing | Map of recovery hotspots/coldspots and comparison with socio-economic, environmental and infrastructural development hotspots/coldspots |
| IV) | Compare and contrast community perceptions of socio-economic, environmental and infrastructural development changes and their implications for post-disaster recovery. | Qualitative data | Key informant interviews, focus group discussions, participatory mapping | Matrix of perceived changes and perceived implications for recovery |

Table 3.1: Data, methods and outputs by research objective

### 3.2.3 Thesis methods

An overview of the different quantitative and qualitative methods used in this thesis is provided below.

#### 3.2.3.1 Systematic review

Systematic reviews represent a widely used research method to synthesise available research on a specific topic (Berrang-Ford, Pearce, & Ford, 2015). This research method has been used to document reported losses from SC 1999 as described in Chapter 4 (research objective 1).

The approach used in this study is that of a 'narrative review', which relies on systematic methods for the selection of documents and their inclusion/exclusion criteria, but then uses descriptive analysis to evaluate retained papers, an approach that is particularly well suited when dealing with both quantitative and qualitative literature, like in this study (Berrang-Ford et al., 2015, p. 757).

#### 3.2.3.2 Statistical analysis

A statistical analysis of past socio-economic, infrastructural and environmental development gains and losses has been conducted at the district scale to identify major changes and community hotspots of socio-economic, infrastructural and environmental development (i.e., which communities have changed most and why). This was used to achieve research objective 2.

Available national census data from 2001 and 2011 have been used for the purpose. A data-driven approach was adopted to identify parameters based on available data. All data were standardised, a correlation analysis was run and an index was created by combining retained parameters. Values were statistically compared across space to identify which communities experienced the highest and lowest degree of change over the study period.

The full methodology is outlined in the related substantive chapter (Chapter 5).

#### 3.2.3.3 Remote sensing

The development of remote sensing techniques has created new opportunities to look back at past disaster events which were understudied (S. Das & Crepin, 2013; J. Duncan, Dash, & Tompkins, 2014; Kundu, Sahoo, Mohapatra, & Singh, 2001a). Satellite remote sensing, in particular, can support quick, high-resolution, large-scale analysis of change (Jacob, 2017; United Nations, 2014; Watmough et al., 2019).

In this thesis, satellite remote sensing was used to quantify post-disaster recovery rates using crop yield as a proxy measure, given that agriculture is the primary source of livelihoods in the study site to address research objective 3. An overview of the techniques used is provided in the corresponding analysis chapter (Chapter 6).

#### 3.2.3.4 Social research methods

Qualitative research methods were used to investigate community perceptions of the socio-economic, environmental and infrastructural changes experienced over the study period and their implications for post-disaster recovery as described in Chapter 7 (research objective 4). An overview of the specific social research methods used is provided in the following sections and further detailed in the corresponding analysis chapter (Chapter 7).

##### 3.2.3.4.1 Site surveys

Site surveys help in getting a visual picture of the study site so as to have a better understanding of local issues and local needs (Clifford, N., Cope, M., Gillespie, T., & French, 2016), with particular reference to availability and access to resources and services, as well as to the existence and functionality of critical and protective infrastructure.

#### 3.2.3.4.2 Semi-Structured Interviews

Semi-structured interviews were conducted to gather information from relevant institutional stakeholders. Semi-structured interviews make use of open-end questions that are targeted to recipients and modulated based on their replies, to allow for spontaneous contributions from interviewees too on issues that they may perceive as most significant for them or of particular interest (World Bank, (Clifford, N., Cope, M., Gillespie, T., & French, 2016)1996). A list of tentative questions that the researcher wished to explore has been prepared ahead of each interview and tailored to each respondent based on their field of expertise, role and responsibilities. The discussion was be shaped based on the interviewee's answers. All participants were requested to sign a consent form prior to starting the interview, to confirm their will to collaborate on the research, to be personally identified with their answers and to be recorded. Topics that were explored included:

- Socio-economic impacts of tropical cyclones on the community;
- Safety nets;
- Strengths and weaknesses of structural protection measures (e.g., tropical cyclone shelters, saline embankments, etc.) in place in the case study area;
- Institutional strengths and gaps in managing disasters;
- Communication of disaster risk related information during the disaster risk management cycle (from ex-ante to ex-post);
- Education and training on disaster risk reduction;
- Adaptation strategies;
- Community dynamics in emergency;
- Disaster response and recovery;
- Gender dimensions of disaster risk management.

#### 3.2.3.4.3 Focus Group Discussions

A focus group discussion (FGD) is a qualitative research method consisting of gathering people together to discuss a specific topic of interest (Clifford, N., Cope, M., Gillespie, T., & French, 2016; Stewart, D.W. and Shamdasani, 1990). The discussion is moderated and it can help in exploring community perceptions on a topic of interest and to collect local views on the issue (Clifford, N., Cope, M., Gillespie, T., & French, 2016; Mansuri & Rao, 2015; Stewart, D.W. and Shamdasani, 1990).

One of the main advantages of an FGD is that it allows for the exploration of how a group think collectively, with people agreeing or disagreeing on the different dimensions of the topic of interest (Clifford, N., Cope, M., Gillespie, T., & French, 2016; Stewart, D.W. and Shamdasani, 1990). As such, it shows the consistency or variation of perceptions among a group of people (Clifford, N., Cope, M., Gillespie, T., & French, 2016; Stewart, D.W. and Shamdasani, 1990).

#### 3.2.3.4.4 Participatory Rural Appraisal

Group activities were conducted with local residents in target villages using Participatory Rural Appraisal (PRA) techniques, i.e. a series of participatory approaches and methods that emphasize local knowledge and enable locals to make their own assessments and plans (Chambers, 1994, 2007a; World Bank, 1996). These tools were used to understand the dynamics that drive disaster recovery at the community level and the interactions between different attributes of recovery as perceived by local residents. While other research instruments such as questionnaire surveys and interviews are extracting tools in which all power and initiative lie in the interviewer, a PRA is an empowering instrument that allows for outsiders to learn about the local context while at the same leaving locals to drive the process (Chambers, 1994, 2007a). Separate gender groups were formed to ensure equal participation and a better diagnosis of local perspectives and needs by gender (Clifford, N., Cope, M., Gillespie, T., & French, 2016; World Bank, 1996). Collective oral consent was recorded at the beginning of each group activity. Activities were designed to further investigate quantitative evidence that emerged from statistical analysis of socio-economic, infrastructural and environmental data. The specific type of activities is outline in the following sub-sections.

##### 3.2.3.4.4.1 Resource/Risk Mapping

A resource map is a tool that is used for facilitating discussion around issues related to availability and access to resources (e.g., water, medical and educational facilities, financial resources, etc.) within a community (Abarquez & Murshed, 2004; Chambers, 1994; World Bank, 1996). Participants are asked to draw a map of their village and to locate resources; they are then invited to discuss as to whether the identified resources are sufficient and accessible to all or which categories of people have more frequent access to one or another resource, particularly by gender. Areas that are most frequently hit by natural hazards, disaggregated by typology (e.g., cyclones, floods, droughts, etc.), are then located on the same map and elements at risk are identified. The purpose of the exercise is not to produce a detailed map of the community, but rather to explore local perceptions and social issues arising from access to primary resources. In view of this, this activity contributed to achieving the following objectives (Abarquez & Murshed, 2004):

- To map resource availability by type and to identify existing resources that may be used during emergencies;
- To map access to resources by type and gender;
- To identify elements at risk from natural hazards and vulnerable members of the community.

3.2.3.4.4.2 Seasonal Calendar and Hazard Mapping

The seasonal calendar is a tool that is used to gather information about seasonal changes in most frequent activities in the communities, with particular reference to livelihood-supporting activities (e.g., agriculture, fishing, migration), as well as the seasonal impact of natural hazards (Abarquez & Murshed, 2004; Chambers, 1994; World Bank, 1996). As such, it contributes to the following objectives (Abarquez & Murshed, 2004):

- To identify most frequent livelihood-supporting activities in the community and their seasonal variation;
- To identify the seasonal impacts of natural hazards.

Hazard mapping is a technique used to understand the impact of different types of natural hazards (e.g., tropical cyclones, floods, droughts, rain gap, etc.) on different types of activities (e.g., land preparation, plantation, fertilising, harvesting, fishing, livestock, vegetable gardens, etc.). In this regards, it helped (Abarquez & Murshed, 2004):

- To understand the impact of natural hazards on each livelihood activity;
- To rank the impact of natural hazards on livelihoods by severity.

3.2.3.4.4.3 Historic Timeline

The historic timeline is a tool used to gather information on past disasters that have affected the community. Participants are asked to remember all significant past events and their impact in chronological order (Abarquez & Murshed, 2004; Chambers, 1994; World Bank, 1996). This activity is useful to achieve the following objectives:

- To learn which disasters caused by natural hazards affected the community in the past;
- To understand progress over time in terms of risk reduction and recovery.

3.2.3.4.4.4 Venn Diagram

The mapping of institutional presence is usually done by means of a Venn diagram, which allows for the exploration of logical relations between a series of different sets: in this case, the relations between institutions and the community (Chambers, 1994; World Bank, 1996). A circle is drawn at the centre of a paper sheet to represent the community and villagers are then invited to draw the most significant services, such as healthcare, bank, etc., in terms of their importance and accessibility. In broader terms, this activity is used also to understand the importance and accessibility of livelihood activities and basic resources for the community (Chambers, 1994). Institutional services are represented as circles, with their distance to the community circle representing their accessibility (high distance equals low accessibility, and vice versa) and the circle's size representing significance (large circle means vital service, small circle points to low importance). The purpose of a Venn diagram for institutional mapping is:

- To map institutional presence in the community;
- To understand dynamics of access to basic services;
- To understand significance of resources, services and livelihood activities and their ranking within the community.

3.2.3.4.4.5 Daily Activity Clock

A daily activity clock is a tool used to understand the daily distribution of most common activities in the community (Chambers, 1994). As such, it is helpful to learn about the type of activities that are done on a daily basis in the village, how they vary by gender and by social groups, and how they can be affected by natural hazards. This tool is used:

- To gain an understanding of which activities are predominant in the community;
- How these activities are disrupted in case of a disaster and how daily routine is altered as a consequence of that.

3.2.3.4.4.6 Infrastructural Analysis

An infrastructural analysis activity has been specifically developed during the scoping fieldwork to address issues arising from existing protective infrastructure in the community and, most notably:

- Cyclone shelters;
- Saline embankments;
- Geo-tube wall;
- Houses (concrete vs. mud houses).

Participants were invited to think about each of the above-mentioned structures one by one and to discuss their strengths, weaknesses and suggestions for improvement. Such an activity was ideated starting from existing resource manuals for field practitioners on participatory disaster risk assessment and participatory disaster risk management planning (Abarquez & Murshed, 2004; ADPC, 2005) to specifically address infrastructural issues in the study site based on existing structures for risk mitigation. The purpose of this exercise was:

- To understand strengths and weakness of each structural measure for disaster risk mitigation that exists in the study site;
- To explore social dynamics around the presence, functionality, use and access of protective infrastructure in place;
- To understand community perception on existing protective infrastructure, their involvement in planning, their needs and recommendations.

3.2.3.4.4.7 Scorecard

Ranking exercises using a scorecard were performed to explore the perceived interactions among the identified key associates of socio-economic, infrastructural and environmental development that have resulted from census analysis, as well as other attributes of change that may be linked to perceived recovery as emerged from literature and from the database of key drivers of recovery collected from a review of relevant scientific papers. This tool was used to investigate areas of change that were not addressed by census analysis and, most notably, the institutional sphere, as well as to explore how key associates of change emerging from the quantitative study are perceived to have an influence on the ability of local communities to cope with and recover from disasters caused by natural hazards.

### 3.2.4 Ethics

This research adhered to the University of Southampton's Research Ethics Policy[1]. Approval to conduct this research was obtained from the University of Southampton ethics committee. The study used information sheets (See Appendix E) to inform participants about the purpose of the study, its requirements and how the information collected was to be used. Since PRA exercises involved repeated visits to the community, participants were told in advance that they might be asked to participate in multiple sessions. Confidentiality of the data collection and anonymity in data reporting were also assured to the study participants. Actual names of individuals were not mentioned in the transcripts. High levels of illiteracy led to the use of an oral consent form (Appendix E) which was read out to the study participants and which they were asked to sign or

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[1] https://www.southampton.ac.uk/about/governance/policies/ethics.page

mark to confirm their understanding and willingness to participate. For key informants interviewed in their official capacity, a separate consent form, which did not insist on anonymity (Appendix E) was provided. For participant observation, a general consent was obtained from the village chief and committee chairpersons.

# Chapter 4: The 1999 super cyclone in Odisha, India: A systematic review of documented losses

## 4.1 Introduction

This chapter aims to identify socio-economic, environmental and infrastructural losses caused by the 1999 Super Cyclonic Storm in the study site (research objective 1).

On a global scale, tropical cyclones and other weather-related hazards accounted for 91% of disasters triggered by natural hazards between 1998 and 2017 (CRED & UNDRR, 2018). While geophysical events cause most fatalities, climate-related disasters are the main driver of disaster-induced direct economic losses, equivalent to 2,245 billion US dollars (or 77% of the total) over the same period, out of which 59% caused by storms (idem).

Yet, these figures could be significantly higher as the majority of disaster losses goes unreported, especially in the case of developing countries where records are available for only 13% of climate-related disasters (idem).

The 2017 (Harvey, Irma and Maria) or 2005 (Katrina, Rita and Wilma) hurricane seasons alone led to 245 and 201 billion US dollars of reported economic losses respectively, showing how individual events can cause massive losses (idem).

Climate change will only worsen the situation as it is widely accepted that precipitation patterns in tropical regions will become more extreme and flooding from tropical cyclones will increase as a result of sea level rise (Elsner, Kossin, & Jagger, 2008; Emanuel, 2005; Gettelman, Bresch, Chen, Truesdale, & Bacmeister, 2017; IPCC, 2018; Knutson et al., 2010; Mendelsohn et al., 2012; Sugi, Murakami, & Yoshida, 2017; Walsh et al., 2016; WMO, 2006; Woodruff et al., 2013).

In light of this, all major international frameworks, including the 2030 Agenda for Sustainable Development, the Sendai Framework for Disaster Risk Reduction 2015-2030, the Paris Agreement and the Addis Ababa Action Agenda, highlight the need to build on prevention and preparedness to reduce future losses (UNISDR, 2015b; United Nations, 2015c, 2015b, 2015a).

The Sendai Framework, in particular, identifies the necessity to substantially reduce 'global disaster mortality', 'direct disaster economic loss' and 'disaster damage to critical infrastructure and disruption of basic services' by 2030 as three out of its seven targets (targets *a*, *c* and *d*) (UNISDR, 2015b).

The conceptual shift from reactive disaster management, focused on response, to pre-disaster action, founded on prevention and preparedness, has led to acknowledging the importance of planning for long-term recovery (UNISDR, 2015b).

The ability to assess recovery is increasingly being identified as a key step towards effective disaster risk reduction (Aldrich, 2016; Garnett & Moore, 2010). It then becomes essential to understand, identify and assess all sets of conditions that contribute to recovery (Abramson et al., 2010; Aldrich, 2016; Amin & Goldstein, 2008). This is because various socio-economic, infrastructural and environmental factors will operate and interact differentially across different disaster and development contexts and can lead to differential recovery rates (Aldrich, 2011, 2016; Berke et al., 1993; Chamlee-Wright & Storr, 2011; Chang & Miles, 2004; A.E. Collins, 2009; Ingram et al., 2006; Marshall & Schrank, 2014; Nakagawa & Shaw, 2004; Quarantelli, 1999, 1989).

Recovery, however, continues to be one of the least studied phases of disaster risk management and the question of which attributes lead to quicker or slower recovery remains largely unanswered (Aldrich, 2016; Cretney, 2017; G. Smith, Martin, & Wenger, 2018).

India is among the top ten countries in terms of absolute losses from disasters between 1998 and 2017, totalling an estimated 79.5 billion dollars (CRED & UNDRR, 2018). The Indian state of Odisha is highly prone to tropical cyclones, which severely hit its coast numerous times in the past years (Chittibabu, Dube, Macnabb, et al., 2004).

The 1999 Odisha Super Cyclonic Storm, which made landfall on the Indian Eastern coast near Paradip, Odisha on 29 October 1999, was the most intense ever recorded tropical cyclone over the North Indian Ocean, with an estimated sustained maximum surface wind speed of 140 knots at the time of landfall and a lowest estimated central pressure of 912 hPa (Kalsi, 2006). The event was classified as a Super Cyclonic Storm according to the cyclone classification by maximum sustained wind speed and pressure deficit adopted by the India Meteorological Department (cf. Chapter 2, Figure 2.2).

The lack of recorded data at the time, however, has led to limited documentation of both hazard and loss information. Available data include official damage data at the District level, but there is no recorded storm surge information (Kalsi, 2006). Total water levels combining storm surge, tides and waves have been estimated by the Odisha State Disaster Management Authority (OSDMA) (Figure 4.1).

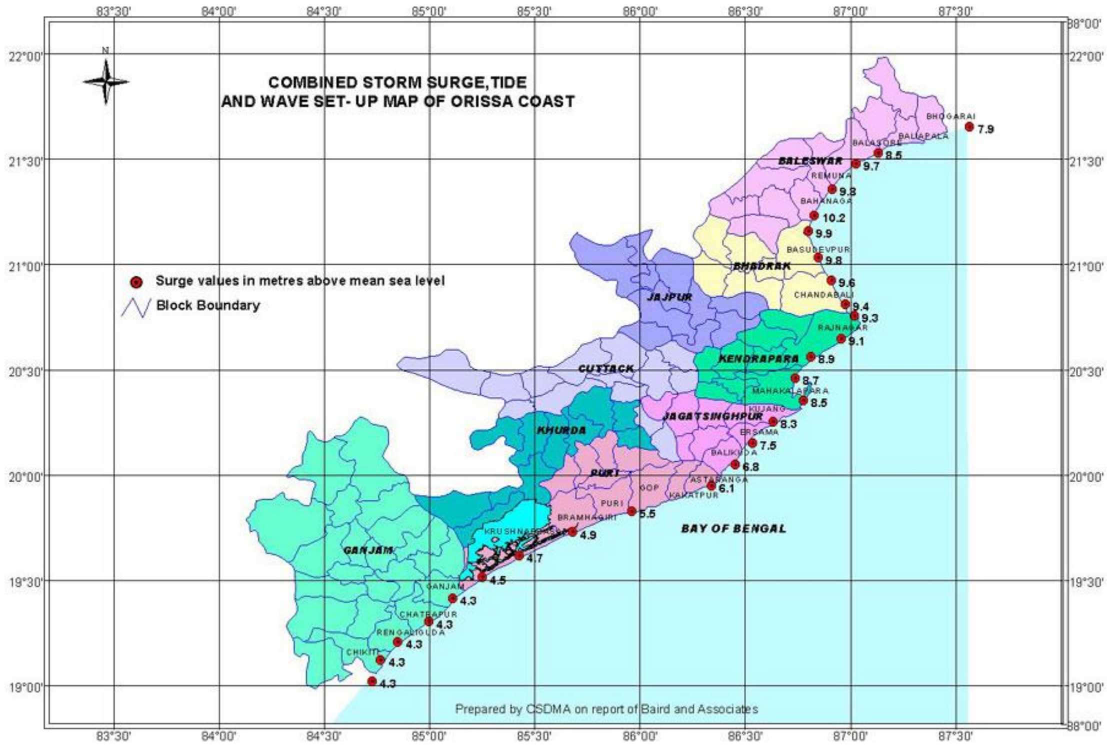



Figure 4.1: Estimated combined storm surge, tide and wave setup along the coast of Odisha further to SC 1999 (OSDMA)

The development of remote sensing techniques has created new opportunities for post-disaster damage assessment using satellite imagery (Amin & Goldstein, 2008; CEOS, 2002; Dash et al., 2004; Joyce et al., 2009; Wulder, Masek, Cohen, Loveland, & Woodcock, 2012) and has generated new studies on the impact of past events using latest technologies (S. Das & Crepin, 2013; J. Duncan et al., 2014; Kundu et al., 2001a). For example, Jangir et al. (2016) used satellite images to understand soil erosion, while a study by Madhu et al. (2002) investigated changes in biological production as a direct consequence of the 1999 cyclone, using chlorophyll-a evidence derived from satellite images.

The State of Odisha has put a lot of effort into creating a disaster risk management structure after 1999, for instance through the establishment of the Odisha State Disaster Management Authority (OSDMA) under the provisions of the 2005 Disaster Management Act and major investments in mitigation strategies (i.e., the construction of flood protection structures and cyclone shelters).

These efforts have led to a significant decrease in mortality from subsequent tropical storms such as cyclones Phailin in 2013 and HudHud in 2014 (NIDM, 2014). Highlighting these disaster management improvements, Odisha was featured as a success story in the 2015 Global Assessment Report on Disaster Risk Reduction (UNISDR, 2015a).

Despite these efforts, disasters caused by natural hazards continue to pose a significant threat to both the population and the state's economy, mostly relying on the primary sector.

A central question that remains unanswered relates to the ability of Odisha to recover after these calamitous events, specifically: do some parts of the state recover more quickly than others? Answering this question is challenging due to the lack of a baseline assessment of social and economic growth and development prior to and after the hazardous events. What would growth have been if the hazards had not occurred? Compiling all documented impacts of the 1999 cyclone over affected communities can serve as a baseline to map net changes in terms of socio-economic, infrastructural and environmental development and determine differential recovery rates over time. This can help identify which areas have recovered faster and why.

Mapping recorded and estimated losses as a consequence of the 1999 cyclone can also contribute to establish a baseline against which to evaluate the effectiveness of the interventions undertaken in the aftermath of this event and the pre-disaster conditions in which communities faced subsequent natural hazards. Twenty years after the event, such a comprehensive review of documented losses has not yet been produced for the 1999 Odisha super cyclone.

To address this major gap, a systematic review of the extent of damages caused by the 1999 super cyclone in the state of Odisha, India has been conducted to gather evidence of impacts. Systematic reviews represent a well-accepted comprehensive approach to look for scientific evidence from literature that is 'as complete and representative as possible of all the research that has ever been done' (Gough, Oliver, & Thomas, 2013, p. 4) and have been widely used in different disciplines for decades (Berrang-Ford et al., 2015; Gough et al., 2013; Moher, Liberati, Tetzlaff, & G., 2009; Porter, Dessai, & Tompkins, 2014).

To map documented losses induced by the 1999 phenomenon on the study site, the following four questions were asked: 1) Which recorded losses did the 1999 Odisha cyclone cause? 2) What is the spatial distribution of these damages? and 3) Which areas have been worst affected? The next section describes the methods used.

## 4.2 Methods

Following Moher et al. (2009), a systematic review was conducted to understand what we know about the extent of damages caused by the 1999 super cyclone in the state of Odisha, India. Systematic reviews represent a well-established approach for rigorous research synthesis (Berrang-Ford et al., 2015) and have been used to harvest literature on disaster losses, albeit predominantly looking at health impacts (see, for example, Neria, Nandi and Galea, 2008; Harville, Xiong and Buekens, 2010; Alderman, Turner and Tong, 2012; North and Pfefferbaum, 2013). The approach used in this study is that of a 'narrative review', which relies on systematic methods for the selection of documents and their inclusion/exclusion criteria, but then uses descriptive analysis to evaluate retained papers, an approach that is particularly well suited when dealing with both quantitative and qualitative literature, like in this study (Berrang-Ford et al., 2015, p. 757).

A keyword search was made using three of the most comprehensive citation databases: Web of Science, Scopus and Google Scholar (Haddaway, Collins, Coughlin, & Kirk, 2015, p. 2). Multiple citation databases were used to ensure increased coverage and it was chosen to include Google Scholar so as to also capture any relevant grey literature on the topic. The list of keywords used and the number of papers returned is provided in Table 4.1. Given the large number of returned papers, only the first ten pages of results from Google Scholar were reviewed.

Table 4.1: Keyword combinations and number of papers found

| **Keywords** | **Database** | **All records** | **Journal articles** |
|---|---|---|---|
| cyclone AND 1999 AND Orissa | Web of Science | 45 | 38 |
| cyclone AND 1999 AND Odisha | Web of Science | 11 | 11 |
| cyclone AND 1999 AND Orissa | Scopus | 62 | 46 |
| cyclone AND 1999 AND Odisha | Scopus | 17 | 11 |
| cyclone AND 1999 AND Orissa | Google Scholar | 5,950 ca. | n/a |

| | | | |
|---|---|---|---|
| cyclone AND 1999 AND Odisha | Google Scholar | 6,530 ca. | n/a |

A total of 106 records were imported into Mendeley (bibliographic software). Inclusion and exclusion criteria were then applied: all papers written in English and focusing on a measure, whether quantitative or qualitative, of the losses induced by the cyclone were included. This included journal articles, reviews, book chapters and conference papers, as well as reports, in an effort to maximise results. Publications outside of the scope of this review were excluded: this included all papers not related to super cyclone 1999 and damage mapping and, in particular, those on other cyclonic storms such as cyclone Phailin or other natural hazards such as floods; and those partially or fully covering super cyclone 1999 but not providing any information on the extent of damages directly or indirectly induced by the cyclone. A total of 32 papers were retained. The full list of returned papers, as well as the list of excluded papers, are provided as in Appendix A.

Interviews with key informants were conducted to capture any outstanding key sources of information. The official memorandum containing damage data at the District level compiled by the Government of Odisha (Government of Orissa, 1999), which is available only *offline*, was added to the retained papers resulting from the *online* search. A total of 33 papers were, thus, analysed.

Limitations of this review include considering only the first ten pages of Google Scholar results and using the English language as one of the inclusion criteria, thus potentially leaving behind relevant grey-literature literature otherwise not captured by the other citation databases as well as literature written in other languages. Another limitation is the fact that some literature, especially reports dating back to the time of occurrence of the cyclone, may not have been digitalised and may not be available online; these documents, however, are often cited as sources of information of retained papers and all those that have been referred to by key informants appear to be captured as such among the retained papers. An overview of the main results is provided in the next section.

## 4.3 Data and metadata

The list of retained papers, including metadata on authorship, year of publication, title and main topic, is provided in Table 4.2 below. All papers are displayed by publication year.

Table 4.2: Retained papers

| ID | Author(s) | Year | Title | Publisher |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 0 | Parida et al. | 2019 | Investigating the effects of episodic Super-cyclone 1999 and Phailin 2013 on hydro-meteorological parameters and agriculture: An application of remote sensing | Remote Sensing Applications: Society and Environment |
| 1 | Ray-Bennett | 2018 | Disasters, Deaths, and the Sendai Goal One: Lessons from Odisha, India | World Development |
| 2 | Irshad | 2017 | Economic recovery of disaster survivors: a critical analysis | International Journal of Emergency Management |
| 3 | Jangir et al. | 2016 | Delineation of spatio-temporal changes of shoreline and geomorphological features of Odisha coast of India using remote sensing and GIS techniques | Natural Hazards |
| 4 | Markose et al. | 2016 | Quantitative analysis of temporal variations on shoreline change pattern along Ganjam district, Odisha, east coast of India | Environmental Earth Sciences |
| 5 | Patra and Jena | 2013 | Health Hazards by Sea Cyclones in Odisha, the Supercyclone and the Phailin | Odisha Review |
| 6 | Chhotray and Few | 2012 | Post-disaster recovery and ongoing vulnerability: Ten years after the super-cyclone of 1999 in Orissa, India | Global Environmental Change |
| 7 | Das | 2009 | Can mangroves minimize property loss during big storms? An analysis of house damages due to the super cyclone in Orissa | Haque and Shyamsundar, Environmental Valuation In South Asia, Cambridge University Press |

| | | | | |
|---|---|---|---|---|
| 8 | Das and Vincent | 2009 | Mangroves protected villages and reduced death toll during Indian super cyclone | Proceedings of the National Academy of Sciences of the United States of America |
| 9 | Abhyankar, Patwardhan, Inamdar | 2008 | Monitoring changes in rice due to tropical Cyclone using Radarsat-1 SAR data | 29th Asian Conference on Remote Sensing 2008 |
| 10 | Khuntia et al. | 2008 | Incidence, serotype, antibiogram and toxigenicity of Vibrio cholerae during 2000, six month after the super cyclone, 1999 in Orissa, India | Journal of Pure and Applied Microbiology |
| 11 | Mohanty et al. | 2008 | Monitoring and Management of Environmental Changes along the Orissa Coast | Journal of Coastal Research |
| 12 | Ganguli and Chander | 2007 | Impact of natural disasters on livestock farmers: The case of Orissa supercyclone of 1999 in India | Indian Journal of Animal Sciences |
| 13 | Abhyankar, Patwardhan and Inamdar | 2007 | Qualitative approaches to rapidly identify completely submerged rice due to tropical cyclone using satellite data | 2007 IEEE |
| 14 | Das | 2007 | Mangroves - A Natural Defense against Cyclones: An investigation from Orissa , India | South Asian Network for Development and Environmental Economics (SANDEE) Policy Brief Series |
| 15 | Kar et al. | 2007 | Post-traumatic stress disorder in children and adolescents one year after a super-cyclone in Orissa, India: exploring cross-cultural validity and vulnerability factors | BMC Psychiatry |

| | | | | |
|---|---|---|---|---|
| 16 | Abhyankar, Patwardhan and Inamdar | 2006 | Classification of rice crops based on submergence due to tropical cyclone using remotely sensed data: An Indian case study | Proceedings Volume 6412, Disaster Forewarning Diagnostic Methods and Management |
| 17 | Abhyankar, Patwardhan and Inamdar | 2006 | Identification of Completely Submerged Areas<br>Due to Tropical Cyclone using Satellite Data: An<br>Indian Case Study | 2006 IEEE |
| 18 | Kalsi | 2006 | Orissa super cyclone – A Synopsis | MAUSAM |
| 19 | Badola and Hussain | 2005 | Valuing ecosystem functions: An empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India | Environmental Conservation |
| 20 | Das | 2005 | Socio-Economic Devastation of Orissa Coast, India: Caused by Unprecedented Sea Level Rise during October 1999 Super Cyclone | World Water and Environmental Resources Congress |
| 21 | Thomalla and Schmuck | 2004 | `We all knew that a cyclone was coming': Disaster preparedness and the cyclone of 1999 in Orissa, India | Disasters |
| 22 | De, Khole and Dandekar | 2004 | Natural Hazards Associated with Meteorological<br>Extreme Events | Natural Hazards |
| 23 | Kar et al. | 2004 | Mental health consequences of the trauma of super-cyclone 1999 in Orissa | Indian Journal of Psychiatry |
| 24 | Panigrahi | 2003 | Disaster management and the need for convergence of services of welfare | Social Change |

| | | | | |
|---|---|---|---|---|
| | | | agencies - A case study of the Super Cyclone of Orissa | |
| 25 | Sehgal, Sugunan and Vijayachari | 2002 | Outbreak of leptospirosis after the cyclone in Orissa | National Medical Journal of India |
| 26 | Lakshmanan and Shanmugasundaram | 2002 | A model for cyclone damage evaluation | Journal of the Institution of Engineers (India) |
| 27 | Chhotray et al. | 2002 | Incidence and molecular analysis of Vibrio cholerae associated with cholera outbreak subsequent to the super cyclone in Orissa, India | Epidemiology and Infection |
| 28 | Das | 2001 | Impact of super cyclone on groundwater in Orissa, India - a case study | New Approaches Characterizing Groundwater Flow |
| 29 | Kundu et al. | 2001 | Change analysis using IRS-P4 OCM data after the Orissa super cyclone | International Journal of Remote Sensing |
| 30 | Nayak, Sarangi and Rajawat | 2001 | Application of IRS-P4 OCM data to study the impact of cyclone on coastal environment of Orissa | Current Science |
| 31 | World Health Organization | 2000 | Leptospirosis, India. Report of the investigation of a post-cyclone outbreak in Orissa, November 1999 | Weekly Epidemiological Record |
| 32 | Government of Orissa | 1999 | Memorandum of damages caused by the super cyclonic storm of rarest severity in the state of Orissa on 29-30th October, 1999 | Government of Orissa (*offline*) |

Two papers among the retained ones (Ganguli & Chander, 2007; Lakshmanan & Shanmugasundaram, 2002) could not be retrieved online and it was not possible to get access to an additional paper, either through writing to the author or through journal open access (B. P. Das, 2005). Requests for access were sent to the authors of these papers. Due to lack of access, the articles were not further considered.

Furthermore, results from the two returned articles on soil erosion (Jangir et al., 2016; Markose, Rajan, Kankara, Selvan, & Dhanalakshmi, 2016) have not been included in this study's findings, since both articles investigate soil erosion changes over a period of time that comprises 1999, but do not look at gathering specific evidence of those changes before and after the cyclone itself, thus accounting for cyclone-induced losses. In particular, Jangir et al. (2016) considers the Districts of Kendrapara, Paradeep, Puri and Ganjam over the period 1990-2009, using Landsat TM satellite images from November 1990, November 1999 and October 2009, thus using only one data point for 1999 and not looking at understanding soil erosion induced by the 1999 cyclone alone. On the other hand, Markose at al. (2016) limits the analysis to Ganjam District extending the study period to 1990-2014, but using the same satellite images from November 1990 and November 1999, in addition to subsequent ones from 2006 on.

Overall, most studies (sixteen) have been published in environment/natural sciences- related journals, followed by health-related journals (six), disasters and emergency management (three), development and social change (two), remote sensing (two) and engineering (one), in addition to the official memorandum from the Government of Odisha. The peak of research happened closer to the event, between 2001 and 2008, with a decrease in the number of studies per year afterwards. It is worth noting that for some of the more specialised areas of focus, notably remote sensing and averted losses due to mangrove protection, the authorship of papers is less varied. Finally, all retained papers use single-method approaches to gathering data, ranging from remote sensing techniques or secondary data reviews to interviews or focus group discussions, while none of the papers uses mixed methods to overcome some of the limitations in data availability.

## 4.4 Results

**Research question 1: Which recorded losses did the 1999 Odisha cyclone cause?**

Official government data on the damages induced by the 1999 cyclone at the District level are available offline and include recorded losses in terms of human life, livestock, physical assets (houses, water pumps, schools, etc.) and agricultural damage (Government of Orissa, 1999). Other data at the State or District scales are available from other studies; however, extremely limited data are available at the municipality scale due to lack of recording in the aftermath of the event and the challenges of identifying suitable methods for scaling research down in a data-poor context for subsequent studies.

An overview of the type of losses for which data are available from the reviewed papers and the number of articles providing information on those type of losses by scale (State, District, Block or town/village) is given in Table 4.3. The detailed data by loss type gathered from all reviewed papers is annexed to this article (Appendix B).

Table 4.3: Disaster loss types, their spatial scale and related key findings from retained papers

| Loss type | State | District | Block | Town/village | Total | Key findings |
|---|---|---|---|---|---|---|
| Mortality | 13 | 6 | 0 | 2 | 12 | Official data available at district level (Balasore: 49; Bhadrak: 98; Cuttack: 456; Dhenkanal: 51; Jagatsinghpur: 8,119; Jaipur: 188; Kendrapara: 469; Keonjhar: 31; Khurda: 91; Mayurbhanj: 10; Nayagarh: 3; Puri: 301; total: 9,866) (Government of Odisha, 1999). Village-level data available but not published for 409 villages in the Kendrapara District (Das and Vincent, 2009) and for selected villages in Jagatsinghpur District (Chhotray and Few, 2012). |
| Physical injuries | 5 | 1 | 0 | 0 | 5 | Figures vary greatly among studies, ranging from over 2,500 to over 7,500 people injured within the state. According to Das (2001), most injuries (over 1,500) occurred in the Cuttack District. |
| Other health impacts | 3 | 1 | 0 | 2 | 7 | Post-traumatic stress disorder, psychiatric morbidity, depression, leptospirosis, V. cholera, diarrhoea. |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Cholera* | 2 | 0 | 0 | 0 | 2 | Incidence of V. cholerae six month after the super cyclone was found significantly higher than the pre-cyclonic period. 97,000 attacks and 81 deaths due to diarrhoea between November and December 1999 (Chhotray and Few, 2012). |
| *Leptospirosis* | 0 | 0 | 0 | 2 | 2 | Found in selected villages of Jaipur District (WHO, 2000; Sehgal, Sugunan and Vijayachari, 2002). |
| *Post-traumatic stress disorder* | 1 | 1 | 0 | 0 | 2 | Prevalence ranging from over 30% to over 40% in Jagatsinghpur, Balasore, Bhadrak, Jaipur, Kendrapara and Khurda districts (Kar et al., 2007, 2004). |
| *Anxiety, depression or other* | 2 | 0 | 0 | 0 | 2 | Anxiety, depression and abnormal behavioural patterns recorded up to one year after the cyclone (Patra and Jena, 2013). Correlation with post-traumatic stress disorder. |
| Total economic losses | 5 | 0 | 0 | 2 | 5 | Estimated at Rs. 39.68 billion (Kar et al., 2004, 2007). |
| Infrastructural damages | 11 | 4 | 0 | 2 | 11 | Between 1.3 and 1.9 billion houses damaged. Official data available at district level (Government of Odisha, 1999). One quantitative study at village |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | level in the Kendrapara District (Badola and Hussein, 2005). |
| *Houses* | 9 | 4 | 0 | 2 | 9 | |
| *Schools* | 2 | 1 | 0 | 0 | 3 | |
| *Other public buildings* | 3 | 1 | 0 | 0 | 4 | |
| *Roads* | 3 | 1 | 0 | 0 | 4 | |
| *Water infrastructure (dams, flood embankments, etc.)* | 4 | 0 | 0 | 0 | 4 | |
| *Power supply* | 3 | 1 | 0 | 0 | 4 | |
| *Hospitals* | 0 | 1 | 0 | 0 | 1 | |
| *Railway/airport* | 1 | 0 | 0 | 0 | 1 | |
| Agricultural losses | 8 | 7 | 0 | 1 | 13 | 1.84 million ha agricultural area affected (Parida et al., 2019; Government of Odisha, 1999). Official data available at district level (Government of Odisha, 1999). |
| Other vegetation losses | 5 | 2 | 0 | 1 | 9 | Between 9 and 90 million trees uprooted. Village-level data available for three villages in the Kendrapara District (Badola and Hussein, 2013). |
| Livestock losses | 8 | 1 | 0 | 1 | 10 | Between 200,000 and 440,000 cattle lost. |
| Other losses | 2 | 0 | 0 | 0 | 2 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Fishing boats/nets* | 2 | 0 | 0 | 0 | 2 | Over 9,000 fishing boats damaged (Irshad, 2017; Paniraghi, 2013). |
| Averted losses | 0 | 3 | 0 | 0 | 3 | Estimated at 211 saved lives and Rs. 1,800,000 in averted damages (Das, 2007). |
| **Total** | **21** | **13** | **0** | **6** | **28** | |

**Research question 2: What is the spatial distribution of these damages?**

The worst affected District of Odisha was Jagatsinghpur, which reported the highest level of mortality associated to the cyclone with 8,116 victims out of 9,885 state-wise (Government of Orissa, 1999). The District of Kendrapara, however, experienced the greatest degree of damages to houses and followed Jagatsinghpur as the second most severely impacted district in terms of loss of life, with 469 officially documented casualties (Government of Orissa, 1999).

The vast majority of the studies analysed in this paper have focused on the most affected districts, while even scarcer information is available for the other seriously but relatively less impacted regions. Overall, documented losses caused by the 1999 cyclone are available at the State and District levels. However, there is a lack of data at sub-District level.

Out of the thirty-two retained papers, only five studies analyse village-level impacts: more specifically, Irshad (2017) considers three villages in the Ersama Block in the Jagatsinghpur District to investigate economic losses based on lost asset value; Chhotray and Few (2012) use two villages, one in the Ersama Block in the Jagatsinghpur District and one in the Kantapada Block in the Cuttack District as case studies to look at trajectories of livelihoods and shelter for long-term recovery, although it does not dig into documenting losses and provides only qualitative information; Badola and Hussain (2005) estimated household-level losses in three villages in the Kendrapara District, with a quantification of the economic damages incurred by the sampled households, including disaggregation in terms of impact on houses, livestock and other private property; finally, the World Health Organisation (WHO) (2000) as well as Sehgal, Sugunan and Vijayachari (2002) investigate health impacts in four villages in the Jaipur District, looking at the outbreak of leptospirosis as a consequence of the cyclone. This shows the sporadic nature of data available at a sub-District scale, with information available only for selected communities in the Ersama Block of Jagatsinghpur District and the Kantapada Block of Cuttack District, in addition to target villages in the Kendrapara and Jaipur Districts. The lack of a systematic approach to site selection, the limited scale of the studies and their very different research focus do not allow for any spatial comparison of results at the town/village scale.

However, findings from these studies suggest that official records and further analysis at the macro-level (at the District and State scales) fail to capture micro-level losses at the community level. Irshad (2017), for instance, finds that assets owned by the assessed communities were too limited, even before the cyclone, to contribute to the State's economy, despite being a key contribution to household economic security. Their loss and consequent impact on livelihoods, therefore, may not be reflected in official statistics. When comparing the market value of lost assets between 2013 and 1999 for selected villages in the Ersama Block of Jagatsinghpur District, the loss in asset value of crop land, housing and livestock was found to be close to 50% of the community's asset base, meaning that these communities have been pushed economically backward with long-term cumulative impacts on their economic recovery (Irshad, 2017). This is in line with findings from Chhotray and Few (2012) for selected sites in the Ersama Block of Jagatsinghpur District and the Kanatapada Block of Cuttack District.

Overall, Badola and Hussain (2005) is the only study providing more detailed information on the level of damage within the assessed communities, showing that damage to houses was found to be relatively limited, whereas the most significant impacts were on agricultural crops, with flood water levels in fields ranging between 1.09 and 1.99 m.

A number of additional studies relying on the use of remote sensing techniques do, however, provide further insights into the spatial distribution of losses. Seven papers among those retained use satellite-derived data to investigate impacts on rice crops (Abhyankar, Patwardhan and Inamdar, 2008, 2007, 2006a, 2006b) or, more generally, on vegetation (Mohanty et al., 2008; Abhyankar, Patwardhan and Inamdar, 206a, 2006b; Kundu et al., 2001; Nayak, Sarangi and Rajawat, 2001). In particular, Kundu et al. (2001) and Nayak, Sarangi and Rajawat (2001) use the normalised difference vegetation index (NDVI) as a proxy measure of losses (Figure 4.2).

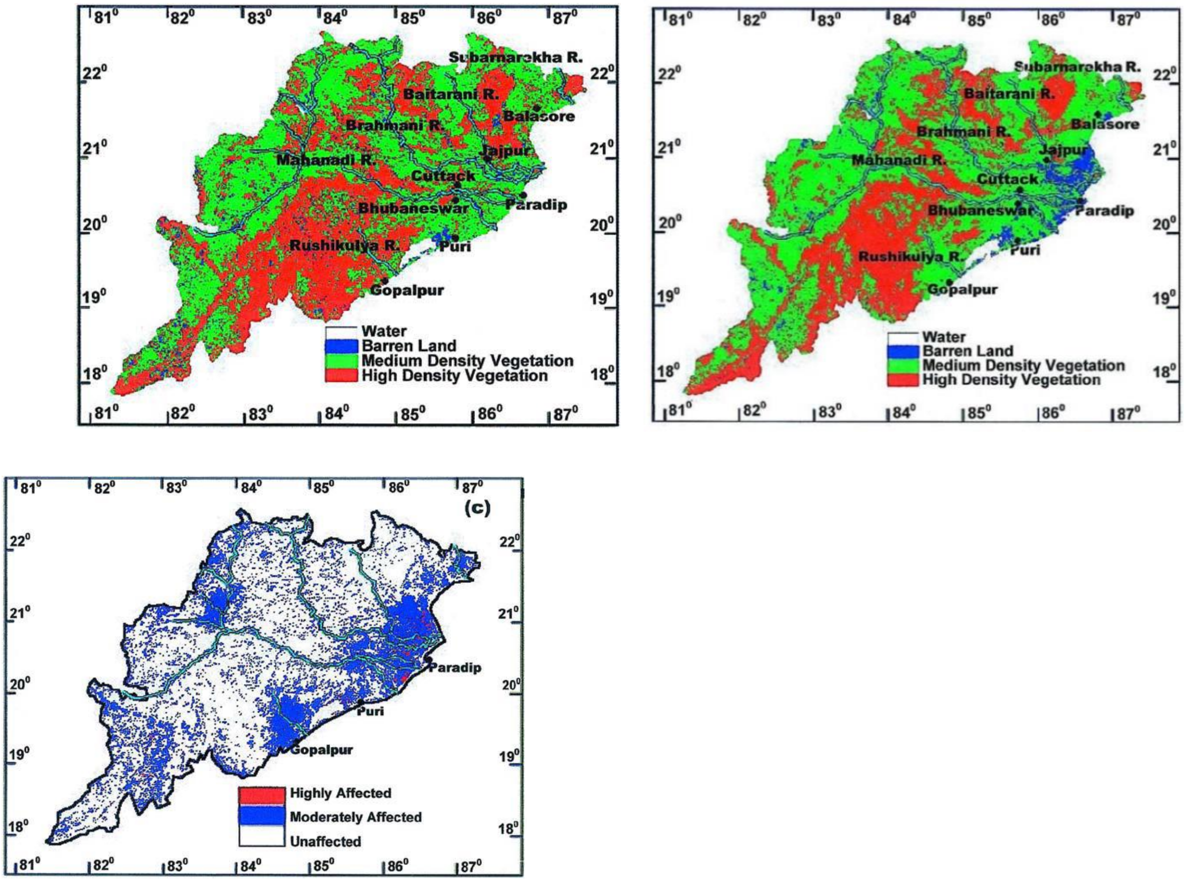



Figure 4.2: NDVI classes at State level for (a) October 1999; (b) November 1999; (c) NDVI difference between pre- and post-cyclone, showing regions affected by the cyclone (Kundu et al., 2001)

**Research question 3: Which areas have been worst affected?**

*Mortality*

The availability of official records allows for an understanding of the spatial distribution of losses across Districts. This shows that the Districts of Jagatsinghpur, Kendrapara, Cuttack and Puri were the ones which suffered the most severe human losses (8,119; 469; 456; and 301 fatalities, respectively) (Government of Orissa, 1999).

*Infrastructural losses*

The Districts of Jagatsinghpur, Kendrapara, Cuttack and Puri also experienced the greatest infrastructural losses (230,508; 345,040; 332,255; and 134,841 houses damaged, respectively) (Government of Orissa, 1999).

*Agricultural, other vegetation and livestock losses*

In terms of agricultural losses, the most impacted Districts were Cuttack (2.09 thousand hectares of agricultural land lost), Mayurbhanj (2.07), Jaipur (1.88) and Bhadrak (1.83) (Government of Orissa, 1999).

Those studies which used satellite images and remote sensing techniques to determine vegetation losses show that, as expected, coastal areas are most impacted and they confirm that Jagatsinghpur, Kendrapara, Cuttack, Jaipur and Bhadrak were the worst affected Districts, providing for the first time further insights in the spatial distribution of losses across these Districts, thus downscaled compared to official records (Figure 4.2c).

Limitations in data availability and the lack of a systematic approach to quantify losses at the sub-District level, with the few studies available at a lower scale focusing on specific areas, typically the most affected, do not permit any further interpretation of the spatial distribution of losses. Therefore, these data should be seen only as a rough interpretation of impacts. It is worth noting, however, that the data presented in this systematic review is the most comprehensive assessment of impacts of the 1999 super cyclone.

## 4.5 Discussion

This systematic review of available literature shows that, twenty years after the 1999 cyclone, the documentation of the losses induced by the cyclone is still limited. It is, therefore, likely that the losses that have been documented are unlikely to be improved. This points to a major documentation gap, which limits our ability to investigate long-term recovery from the event using available data and shows the need to develop innovative approaches adapted to data-poor contexts.

Three main findings emerge from this review: i) for the first time, we are able to map land cover changes before and after the cyclone; ii) coastal districts are proven to be the most impacted, and iii) we now have an understanding, albeit partial, of the health impacts associated with the 1999 cyclone.

Thanks to remote sensing techniques, the spatial distribution of land cover changes has been derived from satellite images through correlation with vegetation indexes. This allows for considerations on the downscaled distribution of agricultural losses, which, however, have not been estimated accordingly to integrate official district-level data. In comparison, much more substantial information on agricultural impacts have been made available in the immediate aftermath of other events, such as hurricane Katrina in 2005, for which detailed assessments of the impacts on agriculture, including on agricultural markets and energy prices, were performed (see, for example, Schnepf and Chite, 2005). This is in line with findings from literature that show that disaster loss records are available for only 13% of climate-related disasters in developing countries (CRED & UNDRR, 2018) and can also be partially explained by advancements in loss accounting over time (Gall, Borden, & Cutter, 2009).

As expected, coastal districts were the worst impacted, particularly close to Paradeep (Kundu, Sahoo, Mohapatra, & Singh, 2001b; Nayak, Sarangi, & Rajawat, 2001). This is not different to what experienced in other similar storm events. However, with Odisha being highly prone to tropical cyclones, this reminds us that the agricultural sector is highly vulnerable to these weather events, as demonstrated for the 1999 cyclone by Abhyankar, Patwardhan and Inamdar (2008, 2007, 2006a, 2006b) and Badola and Hussain (2005). While agriculture contributed to less than 20% of Odisha's Gross State Domestic Product, the share of workers employed in the agricultural sector out of the total working population was 58% in 2001, according to the national census closest to the event date. Agriculture was, therefore, the primary source of livelihood for the population.

Finally, this study contributes to mapping what we know about the health impacts associated with the 1999 event. Results from this review show a high incidence of post-traumatic stress disorder, ranging from 30.6% to 44.3% of the sampled population. This corresponds to the upper range of values of incidence of mental health disorders in the affected population in the first two years after a disaster, which can vary between 8.6% and 53% according to the literature (Alderman et al., 2012). Besides studies on post-traumatic stress disorder, however, there is a lack of evidence of other longer-term impacts (non-communicable diseases, malnutrition and birth outcomes) induced by the 1999 cyclone.

According to a systematic review by Alderman, Turner and Tong (2012), flooding can cause the following types of health impacts: mortality due to drowning and acute trauma; injuries; toxic exposure; communicable diseases (e.g., cholera, diarrheal disease, hepatitis A and E, leptospirosis, parasitic diseases, rotavirus, shigellosis and typhoid fever, but also wound infections, dermatitis, conjunctivitis and ear, nose and throat infections); water-borne diseases (gastrointestinal diseases, hepatitis A and E, respiratory and skin infections); vector-borne diseases; non-communicable diseases (e.g., cardiovascular disease, cancer, chronic lung diseases and diabetes); psychosocial health; malnutrition; and worse birth outcomes.

Out of these categories, data related to the 1999 cyclone are available only in relation to mortality due to drowning and acute trauma, injuries, few of the above-mentioned communicable diseases (cholera and leptospirosis) and psychosocial health, whereas all other aspects have not been investigated. By comparison, there is a substantial mass of data available to look at the health impacts of hurricane Katrina (see, for example, DeSalvo *et al.*, 2007; Sharma *et al.*, 2008; Xiong *et al.*, 2008; Arrieta *et al.*, 2009; Fox *et al.*, 2009; Murray *et al.*, 2009; Rabito *et al.*, 2010).

While the fatalities by drowning or acute trauma caused by hurricane Katrina (1,833) in 2005 were much lower than those of 1999 (close to 10,000), a 47% increase in proportion of deaths was found in the first year following the hurricane, confirming literature that shows that the mortality rate can continue to increase by up to 50% in the first year after a disaster (Alderman et al., 2012). In the case of Katrina, worse birth outcomes were also found to be significantly correlated with severe exposure to the hurricane (Xiong et al., 2008). The impacts of the 1999 cyclone are, thus, likely to have been under investigated.

Overall, while Governments and other stakeholders worldwide are called to invest in disaster risk reduction measures to save lives and reduce losses induced by disasters, as highlighted in the Sendai Framework (United Nations Office for Disaster Risk Reduction (UNISDR), 2015b) which also sets concrete targets by 2030, the lack of documentation of losses and baseline data against which to monitor progress emerges as a clear outcome of this review for the case of Odisha. This is in line with findings from other studies, notably with Ray-Bennett (2018), who concluded that the disaster management system in Odisha is not accountable, highlighting the need to put in place effective reporting mechanisms to ensure that losses are recorded.

With Odisha being highly exposed to the climate emergency, there appears to be an outstanding need to ensure that adequate monitoring and reporting systems are in place to account for losses from individual disasters while at the same time considering correlation with past events from which the state is still recovering. Recoding disaster losses is essential to target interventions and monitor post-disaster recovery. To support data collection and analysis, the Sendai version of DesInventar, a widely-used tool for disaster information management and the generation of national disaster inventories (Groeve & Poljansek, 2013), was developed as a global disaster loss database. These represent historic, international efforts to move forward on disaster loss data collection and build on the work of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts, established in 2013 to promote advances in loss and damage estimation associated with the adverse effects of climate change. Despite these recent advances on international policy, however, the development of national disaster loss databases and the systematic recording of reliable loss information at fine scale continue to be underdeveloped, particularly in developing countries (Groeve & Poljansek, 2013). Other global datasets such as EM-DAT remain a reference for overcoming the lack of official national data (Groeve & Poljansek, 2013).

While policy changes are being promoted at the international level, national governments have to step these efforts up to enhance reporting. India, in particular, has not reported any data as a contribution to the Sendai Framework Monitor. Odisha has the merit of being the only state of India for which information is available on DesInventar; however, reporting is still very limited, with less than 25% of required information provided. Changes in national policies are required to comply with recommended international standards for recording and reporting of disaster losses.

## 4.6 Conclusion

This systematic review shows that evidence of the losses caused by the 1999 super cyclone is lacking at the meso- and micro-level (village and household scale), with most information available only at the macro-level (State and District scale) and mostly focusing on mortality data. While an increasing number of studies has been undertaken to further investigate this disaster event in light of recent technological progress, which has paved the way for new applications to understand past disasters, efforts are predominantly made to model the hazard rather than to assess its impact on people and assets. The spatial distribution of infrastructural and health impacts at the sub-macro level, in particular, appears to be limited, while more information is available on agricultural losses based on estimations from remote sensing.

Only thirty-two papers matched our search criteria, while the large majority of returned contributions was towards an understanding of the physical hazard. Official data are available only at the District level, while no information was recorded at the village level. Results confirm that village-level evidence of losses has not been sufficiently documented and more research is needed to develop methods and tools to assess damages and establish baselines to investigate recovery patterns. The availability of a critical mass of data from satellite images and the development of remote sensing techniques have fostered new studies to derive additional information so as to integrate limited past observations and investigate longer-term recovery in light of newly available data. These studies have, however, been too few for the selected study site so far.

This review, therefore, provides the most comprehensive overview of documented losses induced by the 1999 cyclone and is the best estimate of a baseline of impacts, one that will be challenging to improve given the number of years that have passed since the event and the well-accepted recognition that data consistency across different studies and reliability decrease as older events are investigated (Debarati & Below, 2002; Gall et al., 2009). The authors recognise that it is incomplete and that losses are likely to have been underreported, but this study offers a starting point to understand the impacts and to allow for a comparison with later storms to show progress in disaster risk reduction.

The review could serve as the basis for future studies looking at comparatively evaluating losses from subsequent disasters, such as tropical cyclones Phailin (2013), HudHud (2014) and Fani (2019), which could help shed light on any improvements in disaster loss recording systems, identify patterns of losses occurred in similar cyclones while accounting for enhanced awareness, forecasting, response and monitoring capacities, and draw conclusions on differential impacts accordingly.

# Chapter 5: An analysis of spatial-temporal socio-economic, infrastructural and environmental development changes over the period 2001-2011 in the Kendrapara District of Odisha, India

## 5.1 Introduction

This chapter aims to map socio-economic, environmental and infrastructural development changes through time in the study site and identify hotspots/coldspots (research objective 2).

Disasters induced by natural hazards affect millions of people every year worldwide, causing loss of life and estimated annual economic damages of 250-300 million dollars (UNISDR, 2015a). In view of this, governments and other stakeholders worldwide are placing great emphasis on the necessity to invest in disaster risk reduction. This has been reflected in major international initiatives, such as the Sendai Framework for Disaster Risk Reduction 2015-2030, the 2030 Agenda for Sustainable Development and the Paris Agreement (UNISDR, 2015b; UN, 2015; UNFCCC, 2015).

At the same time and ever since the Brundtland Report in 1987, there has been a global call for sustainable development. The need to re-examine the global challenges for development and to propose realistic solutions to them has been the subject of international efforts over the past thirty years, with a focus on the critical environmental issues that our society is facing (cf. WCED, 1987).

While the discourses of sustainable development and disaster risk reduction present many common opportunities and challenges, as highlighted in the Sustainable Development Goals (SDGs) (UN, 2015), which acknowledge disaster risk reduction as a cross-cutting issue playing a fundamental role for the achievement of most of the SDGs (cf. SGDs 1, 2, 4, 9, 11, 13, 15, 16 and 17), these two disciplines have mostly been treated separately.

The links between development and disasters have been the subject of a large body of literature (cf. Paton et al., 2014; Kapucu & Liou, 2014; Collins, 2009; Fordham, 2007; Schipper & Pelling, 2006; Pelling et al., 2004; Pelling, 2003a, 2003b; Ozerdem, 2003; Fordham, 2003; Stephenson & DuFrane, 2002; Middleton & O'Keefe, 1997).

These studies suggest that socio-economic, environmental and infrastructural development significantly contributes to shaping the way in which people cope with natural hazards and that sustainable development and disaster risk reduction should be pursued together (Collins, 2009; Schipper & Pelling, 2006).

This is because socio-economic, environmental and infrastructural development changes can increase or decrease vulnerabilities and coping capacities, just like disasters can destroy development efforts or create development opportunities, for example for building back better (Stephenson & DuFrane, 2002; cf. UNISDR, 2015a; Goldschmidt & Kumar, 2016).

There is evidence, in particular, that economic development can help reduce the death toll after a disaster (Kahn, 2005; Goldschimdt & Kumar, 2016) and that an understanding of the socio-economic, environmental, and infrastructural development incentives and constraints that regulate an individual's or a community's wellbeing shape their capacity to cope with natural hazards (Barrett & Constas, 2014).

Human wellbeing has been argued to be both a cause and consequence of both disaster and development, in that communities are better prepared to face natural hazards by securing livelihoods, demanding rights, managing risks and adapting to natural hazards (Collins, 2009). These studies prove that good governance can help and suggest investing in community wellbeing as a strategy to reduce disaster risk (Collins, 2009). Disasters therefore become a function of the level of socio-economic, infrastructural and environmental development (Collins, 2009).

Odisha is one of the lowest income States in India, whose economy lags well behind national standards (Government of Odisha, 2011). In recent years, however, the State has experienced significant economic development: while Odisha's Net State Domestic Product (NSDP) experienced a declining trend with respect to national levels for many years, equalling 90% of the country's average in fiscal year 1950-1951 down to 61% of the country's average in 2002-2003, this pattern has been reversed since 2004-2005 when the NSDP began to rise again (Government of Odisha, 2011).

Reasons for this positive change is to be found mostly in the rapid growth of the secondary and tertiary sectors (Government of Odisha, 2011). The boosting of these sectors is contributing to a diversification of revenue sources in a region that is highly vulnerable to tropical cyclones and other natural hazards (cf. Chittibabu et al., 2004), the sector most exposed to which is agriculture (Government of Odisha, 2011).

Despite this shift, the primary sector continues to be the main source of livelihoods, with 51% of the total working population in 2001 being employed in agriculture against a sectoral contribution to the Gross State Domestic Product (GSDP) of less than 20% (Government of Odisha, 2011).

Economic development has contributed to reducing poverty rates in the State, although a rural-urban poverty gap persists, with rural communities being the most challenged (Government of Odisha, 2011, 2004).

These spatial variations are predominantly linked to differential development, particularly with regard to infrastructure and the socio-economic dimensions of poverty (Government of Odisha, 2011, 2004). These differences are further accentuated in the event of natural hazards which unevenly impact communities.

In Odisha, the coastal district of Kendrapara is particularly exposed and vulnerable to tropical cyclones (DECCMA-India, 2015; Chittibabu et al., 2004). Its population predominantly relies on agriculture for livelihoods, which have been significantly impacted during past cyclones (Government of Odisha, 2011).

In October 1999, the District experienced the most intense recorded cyclone on India's coasts, also known as Super Cyclone 1999 (SC 1999) (IMD, 2013). The establishment of the Odisha State Disaster Management Authority (OSDMA) under the provisions of the 2005 Disaster Management Act, as well as major infrastructural developments in the aftermath of SC 1999 (cf. the construction of cyclone shelters and saline embankments along the coast), have led to a significant decrease in mortality associated to natural hazards, from 9,893 fatalities caused by SC 1999 (NIDM, 2013) to 44 lost lives in Odisha as a consequence of Phailin (NIDM, 2013). As a result, Odisha was featured as a success story in the latest Global Assessment Report on Disaster Risk Reduction (UNISDR, 2015a).

Disasters caused by natural hazards, however, continue to pose a significant threat to both the population and local economy, causing loss of livelihoods and widespread devastation (UNISDR, 2015b). Cyclone Phailin in 2013 and cyclone HudHud in 2014 affected 668,268 and 2,370,000 hectares of farmland respectively (IMD, 2013; Times of India, 2014). These challenges in dealing with disaster risk pose significant questions on the impact of natural hazards on development and viceversa.

While an increasing number of researchers, practitioners and policy-makers is advocating for integrating development and disaster risk reduction approaches to improve understanding and target practical interventions, these two issues often continue to be treated separately (Fordham, 2007; Schipper & Pelling, 2006; Goldschimdt & Kumar, 2016).

There is an unfulfilled need to demonstrate how socio-economic, infrastructural and environmental development initiatives ultimately impact their beneficiaries (Beamon & Balcik, 2008). Overall, more research is needed to investigate the impacts and effects of development efforts on disaster risk reduction and to identify which development activities lead to the greatest reduction of disaster risk and increased ability to cope with natural hazards (Goldschimdt & Kumar, 2016).

In a recent study, Few et al. (2016) acknowledge a lack of empirical studies investigating specific initiatives and interventions for capacity development in developing countries and encourage researchers to provide evidence of small but tangible gains and improvements that can help shed light on key opportunities and challenges for building capacities locally.

Context-specific empirical evidence of the implications of socio-economic, infrastructural and environmental development for a community's ability to cope with natural hazards is lacking (Matyas & Pelling, 2015; Weichselgartner & Kelman, 2015).

Overall, there is a lack of systematic studies of the broader socio-economic, environmental and infrastructural development changes on a larger scale to fully understand the heterogeneity and dynamics of their differential impacts on people's capacity to deal with disasters in coastal Odisha.

Given India's fast economic growth and Odisha's exposure to natural hazards, there is a need to determine: 1) how socio-economic, infrastructural and environmental development has varied over time and across different communities in relation to natural hazards; and 2) which communities have experienced the greatest degree of change.

Against this background, the aim of this study is to investigate the spatial-temporal socio-economic, environmental and infrastructural development changes in the Kendrapara District of Odisha between 2001 and 2011. This will be achieved through the following objectives:

1) To create a database of past socio-economic, infrastructural and environmental development gains and losses taking place at the village scale in the Kendrapara District of Odisha;
2) To analyse the spatial and temporal patterns of these development changes and to identify key associates of development and development hotspots/coldspots, using statistical methods.

An analysis of past socio-economic, infrastructural and environmental development gains and losses, acting as incentives and constraints respectively, may contribute to enhancing the understanding of a community's ability to cope with external shocks and stresses (Barrett & Constas, 2014). In particular, the identification of key associates of socio-economic, infrastructural and environmental development changes and major socio-economic, infrastructural and environmental development hotspots, i.e. communities which experienced outstanding changes, may help shed light on their implications for coping with natural hazards.

## 5.2 Methods

A statistical analysis of past (2001 – 2011) socio-economic, infrastructural and environmental development gains and losses has been conducted at the district scale using a data-driven approach to identify major changes and community hotspots of socio-economic, infrastructural and environmental development (i.e., which communities have changed most and why).

Official government census data were used. A quantitative analysis of census datasets from 2001 and 2011 was performed using statistical methods to identify trends and patterns of change across relevant census variables and communities. Provided that this research study is being conducted at the community level, census datasets containing information at a village scale have been considered. In this regard, it must be noted that census data available at such a scale were limited, as compared to the mass of census data available at larger scales, and therefore only population and village amenities census datasets have been taken into account for this analysis. A data-driven approach has been adopted for the investigation of socio-economic, infrastructural and environmental development changes and their attributes over time and space, with the aim of overcoming a researcher-operated selection of communities and/or parameters to rather explore emerging evidence from data and let data inform the analysis and evaluation of development gains and losses, and their associates, as well as the identification of development hotspots/coldspots which experienced the most significant change. Different statistical methods have been employed in conducting the analysis of census data and are detailed in the paragraphs below.

*Dataset preparation and refinement of study area*

The analysis was carried out for the Kendrapara District of Odisha (Figure 5.1) to understand patterns of change.

Three census data points were available: 1991, 2001 and 2011. Census data from 1991, however, could not be used because they were not directly comparable to subsequent ones due to substantial changes in administrative boundaries and village codification, with not enough information available to be able to uniquely identify villages. Specifically, the number of Districts and Blocks changed significantly between 1991 and 2001, with rearrangements in administrative boundaries and a new codification system introduced with the 2001 census that was not directly related to the one used before. Only 2001 and 2011 data were therefore used. The 1991 data could have been used to establish baseline conditions prior to SC 1999. While not being able to use them represents a limitation for the study, the availability of 2001-2011 data still offers the opportunity to look at long-term trends after SC 1999, which provides useful insights into patterns of development and recovery, complemented by subsequent pieces of the analysis (proxy estimation of post-disaster recovery rates) that consider yearly data points from satellite earth observation. Additional population data were available from the Indian Demographic and Health Survey of 1998-1999. However, the survey also used the 1991 census list of administrative units as the sampling frame and it could, thus, not be used for the same reasons as for the 1991 census.

A pre-processing of 2011 and 2001 census population datasets has been performed to create comparable datasets and further refine the geographical coverage of this analysis based on available data. Data for six Blocks out of nine in the District were directly comparable, while data for the remaining three would have required significant adjustments to reflect changes in administrative boundaries (e.g. reclassification of Blocks) that have occurred between the two data points (2011 and 2001).

The outcomes of a hotspot mapping analysis conducted within the framework of the DECCMA project (cf. DECCMA-India, 2015) have been used to understand exposure to natural hazards in these six Blocks, on the grounds that this research study looks particularly at the implications of development for disaster risk reduction and resilience. This hotspot mapping analysis considered different types of natural hazards, among which tropical cyclones, coastal and fluvial erosion, and flooding were the most relevant to this thesis research (which focuses specifically on tropical cyclones and flooding). The analysis looked specifically at which natural hazards each Block was exposed to, then classifying Blocks by their level of exposure to the different types of hazards.

According to this report, the coastal Blocks of Rajnagar and Mahakalapada in the Kendrapara District have been classified as the most exposed to tropical cyclones; the Blocks of Rajnagar, Aali and Rajkanika appear to be the most exposed to coastal and fluvial erosion; while Rajkanika and Aali Blocks are the most exposed to flooding (Figure 5.2). On the other hand, the remaining Blocks were found to be primarily exposed to other types of natural hazards, such as droughts, therefore presenting a different disaster risk profile.

For the purpose of this thesis, the analysis domain was therefore restricted to these four Blocks that are primarily affected by tropical cyclones and related flooding, for which census datasets were directly comparable. The reason why it was restricted only to Blocks that are affected by tropical cyclones and flooding is that the purpose of this thesis is to understand the relative spatial-temporal variations in patterns of development and post-disaster recovery across villages affected by tropical cyclones specifically. The other Blocks have a substantially different disaster risk profile, being mostly exposed to other types of hazards, including droughts. While expanding the analysis to areas that are not or less prone to tropical cyclones may provide benefits for comparison of development changes only, it would require introducing other elements of analysis to account for other more predominant natural hazards.

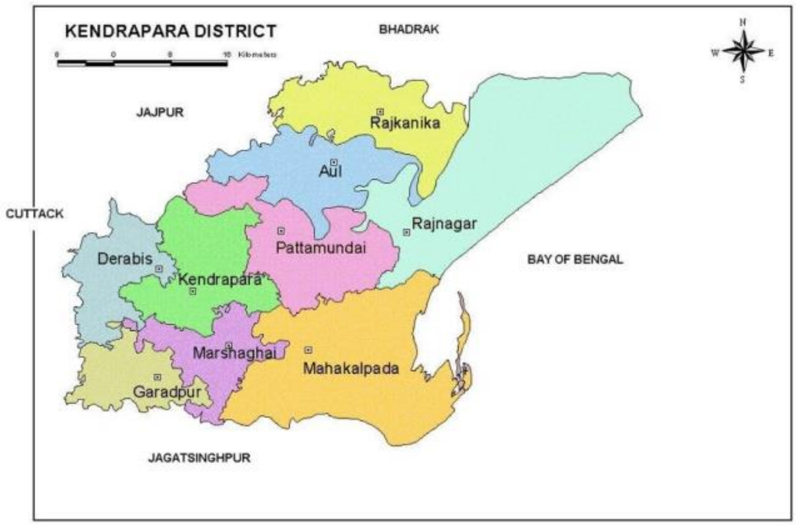



Figure 5.1: Administrative Blocks in the Kendrapara District (Government of Odisha)

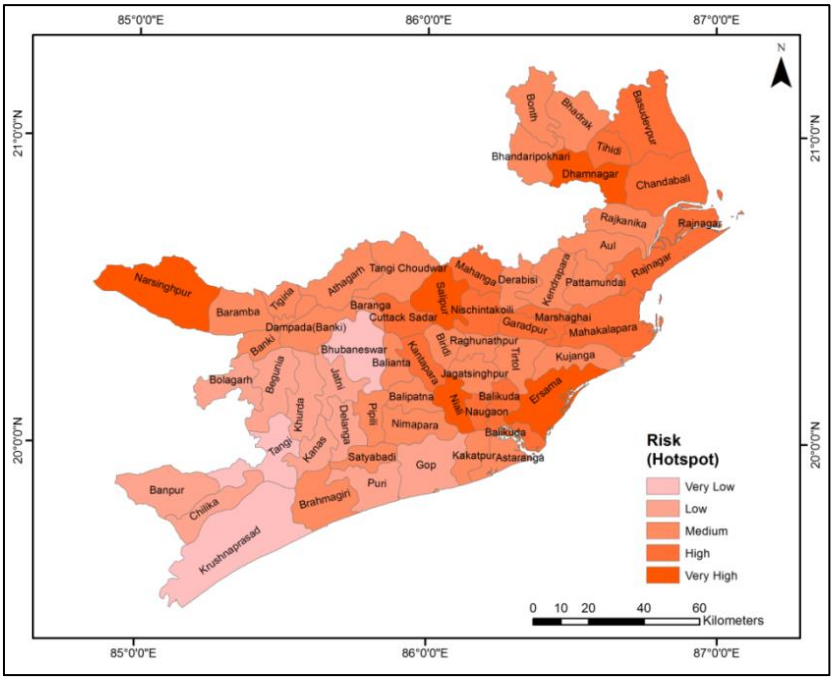



Figure 5.2: Natural hazard hotspots as mapped under the DECCMA project (DECCMA-India, 2015)

A crosscheck between the 2011 and 2001 population datasets led to the removal of all entries for which data were not available for either of the data points. Crosschecking between population and village amenities census datasets led to a further refinement of the analysis village domain. All entries for which land use data were available but which corresponded to a zero population, for which all population data were therefore null, were removed, since this analysis is being conducted at the community level to understand the broad socio-economic factors that may have an influence on community resilience and not just on land use changes. This led to the final selection of entries (i.e. villages). An overview of the initial and final sample size is provided in Table 5.1 as an estimate of the representability of the sample and the extent of the data analysis.

Table 5.1: Total number of villages considered by census data (census entries), number of villages retained after comparison between 2001-2011 census (pre-selected entries) and number of villages selected after cross-verification of village and amenities data (selected entries)

| **Block** | **Census entries** | **Pre-selected entries** | **Selected entries** |
|---|---|---|---|
| Rajnagar | 322 | 255 | **247** |
| Rajkanika | 167 | 155 | **155** |
| Aali | 133 | 122 | **122** |
| Mahakalapada | 187 | 138 | **136** |
| **Total** | **809** | **670** | **660** |

*Selection of relevant census variables*

Relevant census variables were chosen to investigate change across communities over the 10-year time, between 2001 and 2011. A number of parameters, or indicators, were measured to explore how they evolved over time. The choice of variables was aimed at maximising contributions from census data and therefore all census variables relevant to disaster risk reduction were included in the analysis. This effort resulted in the following twenty-seven indicators built from census data, which were then used to understand change (Table 5.2). These parameters were used as a proxy measure for agents of development.

Table 5.2: List of census parameters analysed (in red, those who were removed from further investigation after running a correlation analysis)

**Society**

| **Code** | **Indicator** | **Unit** |
|---|---|---|
| SC1 | Literacy | % population that is literate |
| SC2 | Female literacy ratio | % female literate population out of total literate population |
| SC3 | Age | % adult population (above 6 years old) |
| SC4 | Age - Gender | 100 - % female adult population out of adult population |
| SC5 | Social groups | 100 - % Scheduled Castes/Tribes (SC/ST) |
| SC6 | Social groups - Gender | 100 - % female social minority population out of total social minority population |
| SC7 | Educational equity | Distance to primary school (0:>10km; 33:5-10km; 66:<5km; 100:in the village) |
| SC8 | Adult education and training programs | Community adult educational facilities per capita (industrial schools, training schools, adult literacy classes/centres) |
| SC9 | Hospital access | Distance to (allopathic) hospital (0:>10km; 33:5-10km; 66:<5km; 100:in the village) |
| SC10 | Maternal and childcare | Distance to maternal and child welfare centres (0:>10km; 33:5-10km; 66:<5km; 100:in the village) |
| SC11 | Communication capacity | Distance to telephone access point (landline) (0:>10km; 33:5-10km; 66:<5km; 100:in the village) |
| SC12 | Community services | Availability of community services (recreational and cultural facilities) |
| SC13 | Media | Access to newspapers |

**Economy**

| **Code** | **Indicator** | **Unit** |
|---|---|---|
| Ex EC2 | Employment & gender equality | % female labour force participation |
| EC1 | Employment | % employed |
| EC2 | Work stability | % main workers |
| EC3 | Work stability & gender equality | % female main workers out of main workers population |
| EC4 | Diversification | % population not employed in the primary sector |

| | | |
|---|---|---|
| EC5 | Access to credit | Distance to bank (0:>10km; 33:5-10km; 66:<5km; 100:in the village) |
| Ex EC7 | Access to credit | Distance to agricultural credit societies (0:>10km; 33:5-10km; 66:<5km; 100:in the village) |

**Environment**

| Code | Indicator | Unit |
|---|---|---|
| ENC1 | Forest | ha of land that is non-developed forest |

**Community Capital**

| Code | Indicator | Unit |
|---|---|---|
| CC1 | Health workers | Community health workers and private/subsidised medical professionals per 1000 population |

**Infrastructure**

| Code | Indicator | Unit |
|---|---|---|
| INFC1 | Water access | Water facilities per capita |
| INFC2 | Public transport | Distance to bus/railway services (min) (0:>10km; 33:5-10km; 66:<5km; 100:in the village) |
| INFC3 | Connectivity | Road type (paved vs. mud/other) |
| Ex INFC4 | Electricity | Power supply availability (0: no; 100: yes) |
| INFC4 | Additional sheltering needs | Schools per capita |

*Standardisation of data and correlation analysis*

With regard to data standardisation, all raw data were converted into comparable scales using percentages, per capita and transformation functions. Most raw data had already been compiled in a way that the better development outcome was corresponding to a higher value (e.g., distance to public transport corresponding to a value of 0 out of 100 if very far from village and to 100 out of 100 if in the village), with only few data requiring switching. Since the resulting indicators were therefore expressed on different measurement scales, a Min-Max rescaling (also known as feature scaling) was performed according to the formula below to standardise data to a 0-1 range and create a comparable set of indicators. Min–Max rescaling rescales variables into the same measurable scale ranging between 0 and 1 (with 0 being the worst score and 1 the best score). The benefit of this standardisation method is that all values are annealed within a certain range and, as such, it is particularly apt for standardising data whose distance concentration may greatly vary across different variables (Saranja and Manikandan, 2013). It is also particularly suitable when the data to treat include a mix of binary and non-binary data. When the raw data were binary, the values were maintained unchanged, whereas in all other instances they were rescaled to the 0 to 1 range, performing a linear transformation on the original data.

$$x'_i = \frac{x_i - \min(x)}{\max(x) - \min(x)}$$

Indicator ExINFC4 proved not to be a good measure of change since all communities across the sample switched from 0 to 1 over the study period and was therefore removed from the analysis.

A twenty-six by twenty-six correlation analysis was then executed using Pearson's correlation coefficient (r), with a significance value α of 0.05, to remove all variables found to be highly correlated (r>0.700). Pearson's correlation coefficient is a measure of the interdependence between two variables and represents the covariance of these two variables divided by the product of their standard deviation:

$$r_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y}$$

The results of the correlation analysis are provided in Appendix C. Two couples of parameters (EC1 and Ex EC2; EC5 and Ex EC7) showed high mutual correlation (r =0.74 and r =0.96 respectively). These couples of parameters accounted for a measure of employment (EC1: employment, and Ex EC2: female employment) and access to credit (EC5: bank, and Ex EC7: agricultural credit). Two parameters among the four were therefore removed from further analysis to avoid redundancy. It was decided to remove the parameters accounting for female employment and access to agricultural credit. The correlation analysis helped in reducing variables from n=26 to n=24 for the further steps of the analysis.

*Data aggregation and identification of development hotspots*

A combined index was then calculated from the aggregation of the twenty-four selected indicators, acting as proxies for development agents. The purpose of aggregating all parameters into a combined index is to facilitate the identification of change over space and time: it must be noted that the combined index itself should not be regarded as an attempt to compile all information in a unique and comprehensive measure or to provide a complete overview of significant change, since it is clearly restricted to available data and is far from accounting for all potential factors that may contribute to development, but rather as a means to aid data analysis by using variables as proxy measures to represent the social, economic, environmental and infrastructural changes that took place over the study period and were captured by official government statistics.

The combined index was computed as the average between the twenty-four indicators, using equal weighing for each them to avoid making subjective choices. Different approaches have been used in literature for weighing combined indices, all of which present their strengths and weaknesses. The most common methods have been found to either applying eminence-based frameworks such as the Sustainable Livelihood Framework and aggregating variables around capitals or other pre-set framework categories, or interrogating communities to incorporate local perceptions of the relative weighing of the different variables. The former have been criticised for being eminence-based instead of evidence-based (Weichselgartner & Kelman, 2015), with several studies showing that the relative weighing of the pre-set categories does not often best capture reality (see, for example, Berchoux and Hutton, 2019), while adding an additional level of manipulation to the data as compared to equal weighing. The latter have been found suitable approaches to localise information; however, extensive fieldwork would have been required to interrogate communities in a representative sample of villages suitable for the scale of this study (660 analysed). For these reasons, it was decided to follow a purely data-driven approach to interrogate solely the data, applying equal weighing to all variables, aiming to shortlist hotspots/coldspots and to then conduct fieldwork with local communities as a means to verify findings and so as to increase representability of the fieldwork sample. Further research in the future could look into different weighing methods to contribute to filling what remains a limitation.

The combined index was computed for 2011 and 2001 and the delta between the two data points was calculated, for each of the 660 villages being analysed. The delta between the two combined indices was used as a measure of change across the sample. Standard scores (z-scores) were computed for each entry as per the formula below and were used to facilitate the identification of significant development gains and losses from the sample under consideration.

$$z - score_i = \frac{x_i - \mu}{\sigma}$$

(With $\mu$ = mean of the sample and σ = standard deviation of the sample)

In order to facilitate the identification of significant change, all entries which had a normal score (z-score) above 2 or below -2, were further investigated to understand which factors emerged to have a role in the significant increase or decrease of the combined index over the study period.

Two categories of villages were therefore identified as development hotspots/coldspots based on their standard scores: 1) top performers (or hotspots), for which positive change occurred between 2001 and 2011 (z-score>2); and 2) worst performers (or coldspots), for which negative change occurred between 2001 and 2011 (z-score<-2). A total of 26 villages were identified as development hotspots/coldspots across the four examined Blocks of the Kendrapara District (Rajnagar, Rajkanika, Mahakalapada and Aali). These villages have experienced significant change over the ten-year study period, whether positive or negative, compared to their neighbouring communities. These hotspots/coldspots were further considered for the analysis to identify the main associates of change in each of them.

*Classification methods and identification of key development associates*

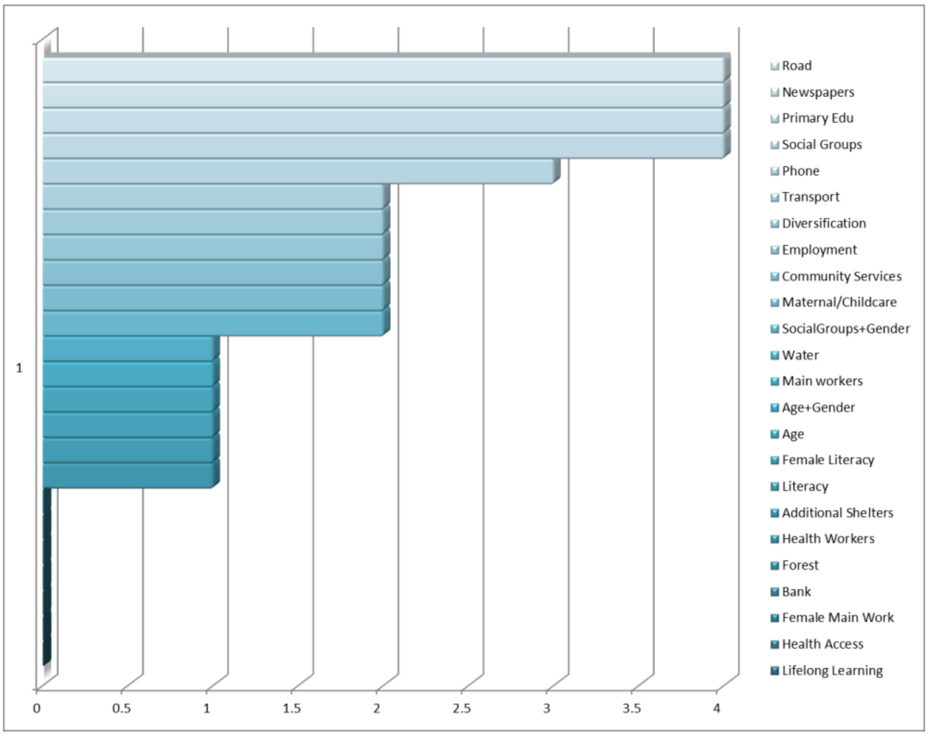
The shortlisting of hotspot/coldspot villages was aimed at further investigating which development gains and losses have driven change over the study period in each community. A cluster analysis was performed using *k*-means clustering, with the aim of classifying the census variables or agents of development into homogeneous clusters. Given a set of observations, *k*-means clustering helps in partitioning the sample of observations into a certain number (*k*) of pre-decided clusters by minimising the squared error function given by the following formula (MacQueen, 1967):

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\|^2$$

(where $x_i^{(j)}$ is an observation point and $c_j$ is the cluster centre)

As there are no theoretical prescriptions on how many clusters to select, an iterative process was adopted and results are shown for a five-cluster classification. Observations were classified into the clusters pictured in Table 5.3.

Table 5.3: Classification of retained census variables into five clusters



| Variable | Cluster |
|---|---|
| Lifelong Learning | 0 |
| Health Access | 0 |
| Female Main Work | 0 |
| Bank | 0 |
| Forest | 0 |
| Health Workers | 0 |
| Additional Shelters | 0 |
| Literacy | 1 |
| Female Literacy | 1 |
| Age | 1 |
| Age+Gender | 1 |
| Main workers | 1 |
| Water | 1 |
| SocialGroups+Gender | 2 |
| Maternal/Childcare | 2 |
| Community Services | 2 |
| Employment | 2 |
| Diversification | 2 |
| Transport | 2 |
| Phone | 3 |
| Social Groups | 4 |
| Primary Edu | 4 |
| Newspapers | 4 |
| Road | 4 |

In order to foster discussion around the main social, economic, environment, institutional and infrastructural associates of development that are typically identified in the literature in relation to disaster risk reduction and resilience (cf. Mochizuki et al., 2014; Kahn, 2005; Ferreira et al., 2013; Kellenberg & Mobarak, 2008; Raschky, 2008; Padli et al., 2010, Cutter et al., 2008, 2010; Chambers 1987; Peacock et al., 2010; Sherrieb et al., 2010, etc.), a qualitative classification of the agents of development identified from census parameters was also performed to group them according to the most recurring themes in the literature. The main advantage of such a classification is that it can be consistent across the quantitative and qualitative parts of this study. Overall, the main categories shown in Table 5.4 were used to classify census variables.

Table 5.4: Qualitative, thematic classification of retained census parameters (colours reflect the colour code used for differentiation in the analysis)

| Classification | Parameters |
|---|---|
| Infrastructure | INFC1, INFC2, INFC3 |
| Vulnerable Groups | SC3, SC4, SC5, SC6 |
| Literacy | SC1, SC2 |
| Health | SC9, SC10, CC1 |
| Employment | EC1, EC2, EC3 |
| Diversification | EC4 |
| Gender | SC2, SC4, SC6, EC3 |
| Environment | ENC1 |
| Credit | EC5 |
| Communication | SC11, SC13 |
| Education | SC7, SC8 |
| Sheltering Needs | INFC4 |
| Cohesion | SC12 |

An analysis of the top five associates of development in each development hotspot was conducted to understand which factors drove change and to which of the above-mentioned theme or category these predominantly belong to. The purpose was to identify key associates of change and to understand the role of infrastructure, education, employment, environment and other relevant aspects in driving this change. The interaction among them was also investigated.

*Sensitivity analysis*

Finally, a sensitivity analysis was performed by removing selected parameters to understand which of those twenty-four independent variables were driving the changes in the dependent index. A sensitivity analysis is a well-established and widely used method that measures the impact that one or more input variables can lead to on the output variables (Saltelli, 2002). As such, it is useful in this context to understand how much the census variables are influencing the aggregated index. One of its main limitations, however, is that it does not consider the interaction between the different parameters, which was qualitatively investigated.

Selected parameters were removed from the calculation of the index and changes in the 2001-2011 delta were computed to understand how this varied and the importance that the removed parameters exercise on the overall index. This was done in an iterative manner by removing different parameters so as to identify and narrow down those that contributed the most to changes in the overall index.

## 5.3 Results

The aggregation of relevant census variables into a combined index, the calculation of the time variation of this index for each community and the use of the z-score as a means to identify villages which experienced significant positive or negative change as opposed to minor to no change in their neighbouring communities led to the identification of key associates of change in those communities. Most of these socio-economic, infrastructural and environmental development hotspots/coldspots are located in the coastal Blocks of Rajnagar and Mahakalapada (Figure 5.3).

| BLOCK | VILLAGE | DELTA 2011-2001 | |
|---|---|---|---|
| Rajnagar | Amanapari | -8% | - |
| | Bagapatia(Uttar) | -11% | - |
| | Balunga Patia | -9% | - |
| | Bimisnagar | -9% | - |
| | Chakradharpur | -9% | - |
| | Daruora | - | 16% |
| | Dhaneswarpur | -9% | - |
| | DurgaPrasad | -8% | - |
| | Kamalpur | -13% | - |
| | Kusunpur | -8% | - |
| | Magarkanda | - | 15% |
| | Maliparida | -14% | - |
| | Taradeipur | - | 18% |
| | Tikayat Nagar | - | 15% |
| Mahakalapada | Jagati | - | 16% |
| | Kansapal | - | 16% |
| | Kharinasi | - | 16% |
| | Kusiapal | -12% | - |
| | Oliha | -7% | - |
| | Suniti(Bena Kandha) | - | 17% |
| Rajkanika | Baranga | -8% | - |
| | Cherantapada | - | 15% |
| | Sialia | -8% | - |
| | Singidi | - | 18% |
| Aali | Kochila | -9% | - |
| | Purilo | -9% | - |

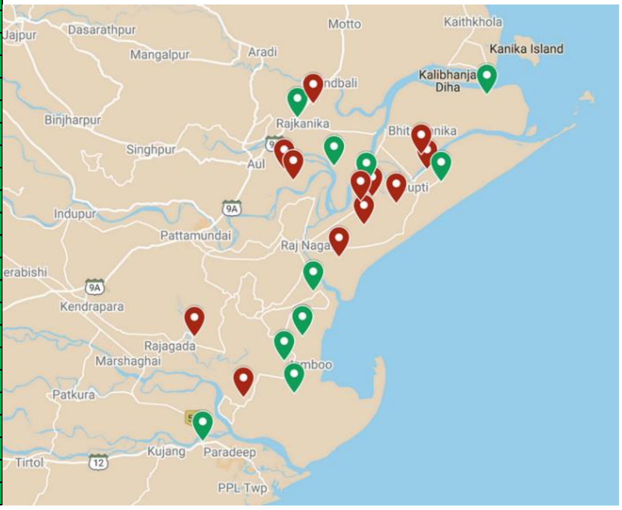
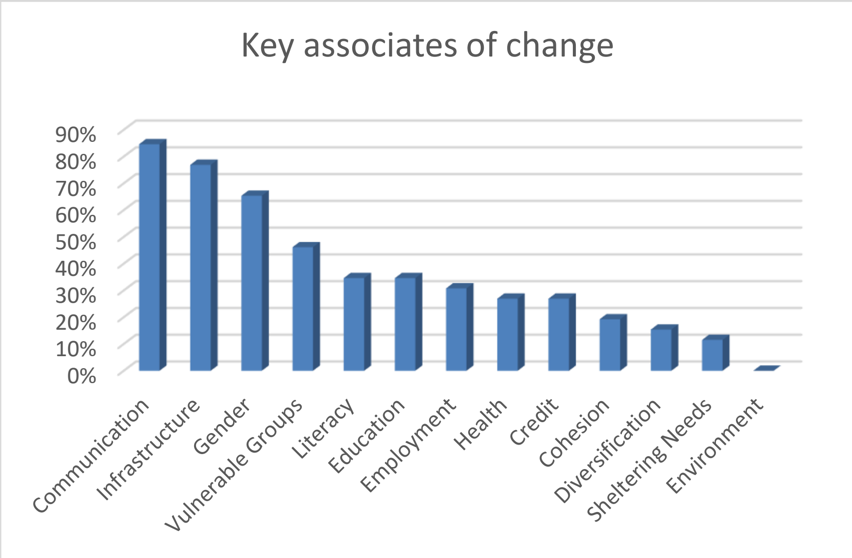



Figure 5.3: List of socio-economic, environmental and infrastructural development hotspots/coldspots (red indicates negative change, green indicates positive change; other colours are used to differentiate the villages by Block), with their geographical distribution (from Google My Maps)

As highlighted in Figure 5.4, the main factors which played a role in the overall socio-economic, infrastructural and environmental development gains or losses as emerged from the quantitative census data analysis were mostly pertinent to the sphere of Communication, Infrastructure, Gender and Vulnerable Groups: by considering the top five parameters (cf. Table 5.4 for the full list of parameters used to build the combined index) which drove change in each of the hotspots/coldspot communities, it was found that in 85% of instances at least one of these top five parameters refers to the sphere of Communication (cf. access to phone, access to newspapers), which is reduced to 77% in the case of Infrastructure (cf. access to water, roads, etc.), 65% for Gender (cf. data disaggregated by gender, e.g. female main workers) and 46% in the case of Vulnerable Groups (cf. age and social groups).

The mutual interactions between these key associates was then explored to look for positive correlation among them and to understand how they combine together. Each associate was used as a baseline to determine which other factors typically interplay with it. Results are described below.




| Key associates of change | |
|---|---|
| Communication | 85% |
| Infrastructure | 77% |
| Gender | 65% |
| Vulnerable Groups | 46% |
| Literacy | 35% |
| Education | 35% |
| Employment | 31% |
| Health | 27% |
| Credit | 27% |
| Cohesion | 19% |
| Diversification | 15% |
| Sheltering Needs | 12% |
| Environment | 0% |

Figures 5.4: Key associates of change in order of strongest association (colours reflect the colour code used for differentiation in the analysis)

The most common associate of change, Communication, proved to be highly correlated with the second key associate of change, Infrastructure (in 69% of instances in which Communication is one of the top five associates of change, Infrastructure also ranks among the major five reasons for change), confirming that access is a major issue for proper communication. Both top factors for change, Communication and Infrastructure, were also found to significantly vary according to gender (58% and 46% respectively) and vulnerable groups (42% and 31% respectively).

When looking at Gender as the baseline, Communication and Infrastructure confirm to be the two most highly ranked co-factors for change, followed by associates for which values disaggregated by gender and thus directly measuring the differential impacts by gender were available in the census datasets (Vulnerable Groups at 38%, Employment at 31% and Literacy at 27%).

In the case of Vulnerable Groups, Communication, Gender and Infrastructure are the most commonly found co-factors for development gains or losses in 42%, 38% and 31% of instances respectively, followed by Employment and Credit both at 19%: this datum confirms that access to credit and job opportunities differ by social groups.

When looking back at Infrastructure as the baseline factor, all major co-factors of change besides Gender (46%) and Vulnerable Groups (31%) refer to the sphere of access (Communication at 69%; Education at 31%; Literacy, Health and Credit at 23%), while employment opportunities do not seem to be greatly impacted by available infrastructure (12%), neither does diversification (15%).

Literacy was to found to be highly related to Communication (35%), Gender (27%) and Infrastructure (23%), with the latter ranking top co-factor on the Education baseline as well (31%), showing that infrastructure-related issues such as access to roads have a major impact on school attendance.

Gender was the top ranking co-associate of change for Employment (31%), followed by Vulnerable Groups (19%), suggesting that advancements in employment rates for women and members of scheduled castes and tribes can drive positive change overall.

Communication (19%), Literacy (15%) and Infrastructure (12%) were the other factors of change mostly impacting Employment, although with relatively low values of correlation: as previously inferred, the minor correlation between Employment and Infrastructure may be explained by the fact that agriculture is the primary source of income in the area and access to agricultural land may not be significantly impacted by available infrastructure or transport.

Infrastructure, however, ranks first when Health and Credit are used as the base (23% in both cases), pointing that factors such as road availability and conditions may greatly affect access to healthcare and credit.

Credit also appears to differ by Vulnerable Groups and Gender (both 19%). It is Infrastructure again which scores highest in the case of Cohesion and Diversification: in the former instance, the availability of community services used as a proxy for community cohesion may be associated with better available infrastructure in general, assuming that investments in basic infrastructure (such as roads) are prioritised against investments in community halls/services; in the latter instance, access to non-agricultural jobs, for which commuting to other communities may be needed, seem to be understandably dependent on infrastructural facilities.

Diversification is equally impacted by Communication (15%), showing that access to information may improve knowledge of available opportunities. Finally, Sheltering Needs appear to be mostly differentiated by Gender (12%), confirming a datum very common in literature (IASC, 2006).

In conclusion, while elements pertaining to the sphere of communication and information appear to be the primary associate of development gains and losses in the study site over the period 2001-2011, improvements in infrastructural conditions seem to have had the greatest impact on all other areas of change, with Infrastructure ranking as the main co-factor of change in 6 instances out of 11 (Communication, Education, Health, Credit, Cohesion and Diversification).

Results from the sensitivity analysis also show that parameters pertaining to the sphere of Communication, Infrastructure and Gender are driving the changes in the socio-economic, environmental and infrastructural development index.

Table 5.5: Results from the sensitivity analysis show that the census parameters pertaining to the spheres of Communication, Infrastructure and Gender drive the changes in the 2001-2011 socio-economic, environmental and infrastructural index

| Block | Village | Delta 2001-2011 | Without Communication | Without Infrastructure | Without Gender | Without Environment |
|---|---|---|---|---|---|---|
| Rajnagar | Amanapari | -8% | 0% | -6% | -9% | -8% |
| | Bagapatia(Uttar) | -11% | -7% | -9% | -12% | -11% |
| | Balunga Patia | -9% | -7% | -9% | -7% | -9% |
| | Bimisnagar | -9% | -2% | -12% | -9% | -9% |
| | Chakradharpur | -9% | -5% | -7% | -11% | -9% |
| | Daruora | 16% | 18% | 12% | 19% | 17% |
| | Dhaneswarpur | -9% | -7% | -10% | -11% | -10% |
| | DurgaPrasad | -8% | -4% | -9% | -7% | -9% |
| | Kamalpur | -13% | -9% | -16% | -13% | -13% |
| | Kusunpur | -8% | -4% | -7% | -9% | -8% |
| | Magarkanda | 15% | 13% | 16% | 15% | 16% |
| | Maliparida | -14% | -6% | -14% | -15% | -14% |
| | Taradeipur | 18% | 19% | 17% | 19% | 19% |
| | Tikayat Nagar | 15% | 12% | 13% | 17% | 16% |
| Mahakalapada | Jagati | 16% | 13% | 11% | 20% | 17% |
| | Kansapal | 16% | 17% | 10% | 15% | 18% |
| | Kharinasi | 16% | 17% | 10% | 18% | 16% |
| | Kusiapal | -12% | -9% | -14% | -15% | -13% |
| | Oliha | -7% | -4% | -8% | -9% | -8% |
| | Suniti(Bena Kandha) | 17% | 14% | 14% | 20% | 17% |
| Rajkanika | Baranga | -8% | -4% | -7% | -7% | -8% |
| | Cherantapada | 15% | 16% | 10% | 18% | 16% |
| | Sialia | -8% | -5% | -7% | -7% | -8% |
| | Singidi | 18% | 11% | 17% | 21% | 19% |
| Aali | Kochila | -9% | -1% | -10% | -11% | -10% |
| | Purilo | -9% | -1% | -7% | -12% | -10% |
| **Average** | | 0,45% | 2,88% | -0,91% | 0,73% | 0,51% |
| **Sensitivity** | | - | 640% | -202% | 163% | 113% |

As shown in Table 5.5, when Communication parameters as mapped in Table 5.4 are removed from the index, the delta between the 2001 and 2011 indices is up to 640% of the original value. When Infrastructure parameters are removed, it goes down to 202% of the original value. When Gender variables are removed, the delta goes up to 163% of the original value. By comparison, when Environment (mapped as the least contributing factor in Figure 5.4) is removed, the delta only increases up to 113% of the original value.

## 5.4 Discussion

Communication, infrastructure and gender emerge as the main associates of socio-economic, environmental and infrastructural change in the study area during the period considered, consistently with the sensitivity analysis performed.

Moreover, infrastructure appears to be the associate of development change that interplays the most with other key attributes. This might be explained by the collateral services that infrastructure offers, for example in terms of access to medical, educational and other facilities.

In terms of communication, the study area has experienced significant improvements in access not only to telephones and newspapers but also to radio and television, which have simplified access to weather forecasts and vital early warning information (Bino Paul and Murti, 2016). In their paper on the socio-economy of mobile phone ownership in India, Bino Paul and Murti (2016) used data from the 2009-2010 National Sample Survey and from the Telecom Regulatory Authority of India to investigate the linkages between socio-economic development and mobile phone penetration. They established a correlation between the density of mobile phone penetration and the Human Development Index across different Indian States, concluding that mobile phones are network goods, with the exponential growth and rapid dissemination of mobile phone ownership transforming lifestyles and livelihoods, especially in the most rural areas. While Odisha continued to have low mobile phone ownership in rural areas (34% versus 72% in urban areas in 2008-2009), it had been on a rapidly increasing trend.

The area also experienced infrastructural developments, including with the construction of new roads improving transport and connectivity as well as protective infrastructure such as embankments and cyclone shelters. As outlined in chapter 2 (section 2.6.1), the combination of improved infrastructure and better access to early warning information has been identified as one of the main drivers of reduced losses from tropical cyclones in the area, particularly when looking at the impact of cyclones Phailin and HudHud (IMD, 2013).

Several studies have investigated the key role played by critical infrastructure (e.g., transport, water and wastewater facilities, public health, emergency services) in successful disaster management, most notably for ensuring communication and the delivery of supplies before, during and after an emergency (cf. Manoj and Hubenko Baker, 2007). Mendonça and Wallace (2006) have found that interdependencies among critical infrastructural systems are a core issue in dealing with infrastructure-related disruptions during emergencies due to the cascade effects they are responsible for, and findings from this quantitative analysis seem to reaffirm this observation.

Infrastructural developments also play a role in reducing distances and, as a consequence, in improving the speed at which the population can access basic services and facilities, and at which humanitarian operations can take place (Goldschimdt & Kumar, 2016). Transportation decisions, in particular, have been found to be fundamental for disaster risk management (Goldschimdt & Kumar, 2016).

Finally, the analysis found that gender and the distribution of vulnerable groups, including minorities, is another of the key attributes of socio-economic, infrastructural and environmental change in the study site. The uneven impact of disasters on different social groups, as well as the need to integrate social vulnerability discourses in disaster and development studies based on the assumption that disaster risk and impacts are distributed in ways that reflect social constructs, has been largely discussed in literature and the disparities deriving from age, gender, class and other shades of social differences behind this differential burden have been widely assessed in practice (cf. Few et al., 2016; Finch, Emrich, & Cutter, 2010; Adger, 2006; Kahn, 2005; Fordham, 2003; Cutter, Boruff, & Shirley, 2003; Hewitt, 1997; Phifer, 1990). Results from the analysis show, on the one hand, that improvements in female labour rates and female literacy are associated with overall socio-economic, infrastructural and environmental development change in the study site, with gender being more strongly correlated with it than other variables of inclusion such as minorities, and, on the other hand, that the distribution of women, girls and other vulnerable groups also significantly influences change, pointing to the key role played by social cohesion towards community development.

## 5.5 Conclusions

In conclusion, theoretical, methodological and empirical gaps persists in literature when looking at the links between disasters and development. As a consequence, isolating associates of development (both actual and perceived) remains a very challenging task, for which several approaches have been used in the literature, primarily relying on eminence-based frameworks built around sets of indicators, of which the Sustainable Livelihoods Framework is one of the most widely known and referenced. The main limitation of these frameworks has been found to be the arbitrary selection of variables and conceptualisation on their interaction.

To overcome these limitations, a data-driven approach has been used in this study to investigate past socio-economic, infrastructural and environmental development gains and losses in the study site and to identify key development hotspots which have experienced significant change, whether positive or negative, over a ten-year period between 2001 and 2011.

Results from this study show that the major socio-economic, infrastructural and environmental development associates in the study site pertain to the domain of communication, infrastructure, gender and vulnerable groups, and present useful insights on the mutual interactions between the different socio-economic, infrastructural and environmental development factors.

This study contributes to providing an evidence-based understanding of socio-economic, infrastructural and environmental development changes in the region and their spatial-temporal characterisation, with the aim of identifying tangible evidence of the differential impact of socio-economic, infrastructural and environmental development on a community's ability to cope with natural hazards.

# Chapter 6: Satellite earth observation and post-disaster recovery from Super Cyclone 1999 in the Kendrapara District of Odisha, India: hotspot/coldspot mapping

## 6.1 Introduction

This chapter aims to estimate differential post-disaster recovery rates, identify recovery hotspots/coldspots, and compare them with socio-economic, environmental and infrastructural development hotspots/coldspots (research objective 3).

From the SDGs to the Sendai Framework, accountability is a cornerstone of implementing the 2030 global agenda (UNISDR, 2015b, 2018; United Nations, 2017). United Nations Resolution 71/313 (United Nations, 2017), adopted by the United Nations General Assembly on 6 July 2017, calls governments worldwide to substantially step up national efforts to actively monitor and report on progress towards achievement of global goals and targets. This requires strengthened monitoring and reporting systems with enhanced coverage and transparency to ultimately deliver on implementation by 2030 (UNISDR, 2018; United Nations, 2016c, 2017). The United Nations has emphasised the need for 'quality, accessible, timely and reliable' data (United Nations, 2017, p. 1) to measure progress and ensure that no one is left behind.

A set of interlinked indicators for alignment in reporting on Sendai global targets against the SDGs has been developed to aid progress measurement (UNISDR, 2018). Minimum standards for reporting have also been produced to set expectations (UNISDR, 2018). These standards define what should be captured to assess progress, as well as suggested methods. However, availability of and access to data to be able to report on those indicators as per the proposed standards and methods remains a major constraint (Jacob, 2017; United Nations, 2014; Watmough et al., 2019). The type of data and metadata gathered by governments through national census and surveys, as well as the frequency of their collection, varies across countries globally (Devarajan, 2013). To comply with the proposed minimum standards, more frequent and finer data are needed (Jacob, 2017; Watmough et al., 2019). National census and surveys, however, are time-intensive and require substantial financial and human resources (Devarajan, 2013). Alternative avenues for higher-frequency and more localised data collection are, therefore, necessary (Jacob, 2017; Watmough et al., 2019).

At the same time, we live in a world of data. The data revolution has generated access to more information than ever before. The United Nations has recognised the opportunity to harvest the potential of big data to support SDG monitoring (Sustainable Development Solutions Network, 2015; United Nations, 2014), with satellite remote sensing as a core solution (Sustainable Development Solutions Network, 2015).

The Sendai Framework identifies the reduction of direct economic losses caused by disasters and impacting gross domestic product (GDP) as one of seven global targets (target ‘c’) (UNISDR, 2015b). One of six indicators developed to measure it is direct agricultural loss attributed to disasters (indicator ‘c2’) (UNISDR, 2018). In places like Odisha, where the agriculture sector employs more than half of the state’s workforce (Government of Odisha, 2017b), quantifying agricultural crop yield losses is a fundamental attribute of reporting on direct economic losses. These losses negatively affect livelihoods, leading to humanitarian impacts that undermine development efforts and require long-term recovery.

Suggested operational guidelines for computing agricultural losses to measure the Sendai indicator ‘c2’ have been produced by the Food and Agriculture Organization (FAO) (cf. UNISDR, 2018, pp. 79–86). These imply availability of pre- and post-disaster input data as a key requirement. For crop stocks, these data include, for example, the number of agricultural hectares, pre-disaster baseline yield, projected or expected yield and actual post-disaster yield. While these guidelines are only intended as a recommendation and national governments may still rely on their own methodologies, countries worldwide are still required to report on the global indicators in line with these minimum requirements, for which similar input data will be necessary. National reporting systems, however, may not be collecting the data that are needed for reporting. The guidelines also notably do not cover potential sources of data by indicator.

Relevant line ministries will typically collect annual harvest data; however, the reliability and spatial resolution of these may not be enough. In Odisha, for instance, these data are available at the Block level, but not at finer resolutions. Official government data are, therefore, not enough to capture the spatial variability of agricultural production in the face of disasters at smaller administrative units, such as at the village level. With an increased focus on localisation (Lucci, 2015), fine temporal and spatial resolution satellite remote sensing can be useful to support monitoring of agricultural production changes, contributing to the SDG and Sendai reporting requirements.

These monitoring activities are fundamental to quantify losses and the time required for recovery. Satellite remote sensing can, thus, substantially contribute to understanding long-term post-disaster recovery. Existing disaster recovery frameworks predominantly focus on combined indices of subjectively selected development indicators without proper investigation of the relationship between these variables and recovery (Aldrich, 2016; Weichselgartner & Kelman, 2015). Their implementation is also constrained by data availability. Satellite remote sensing has, therefore, emerged as a solution for estimating recovery rates (Joyce et al., 2009) using proxies that may vary depending on the context (Ghaffarian et al., 2018). They have been recognised 'as the core of high-resolution agricultural monitoring systems' (Sustainable Development Solutions Network, 2015, p. 93), particularly useful to monitor crop yield changes in the face of disasters (Sustainable Development Solutions Network, 2015). Despite theoretical acknowledgements, studies that estimate long-term recovery rates from satellite remote sensing remain scarce in practice, with most of the literature focusing on assessing short-term disaster impacts, mainly for vegetation (Ghaffarian et al., 2018).

On the other hand, satellite earth observation for agricultural crop monitoring and yield prediction has become the subject of a growing body of literature in recent years, in recognition of the fundamental role played by agriculture in the global economy and its relationship with food security. Optical images remain most used, with Landsat, MODIS and Sentinel-2 as the main data sources; the use of radar data, however, has increased since the emergence of Sentinel-1 starting from 2014, which eliminates cloud cover issues (Zhao, Li & Ma, 2021).

A systematic review of spatial-data based prediction models for crop yield analysis by Mohan and Venkatesan (2020) found that the Normalised Difference Vegetation Index (NDVI) is the most commonly used vegetation index for crop yield prediction analysis. This is in line with similar findings from de Castro et al. (2021), which show that it is more prevalent and reliable than other vegetation indices for crop yield monitoring. Heargreaves and Watmough (2021) also found that NDVI was the most used earth observation data product to proxy agricultural productivity, while Night-Time Lights is best used as a proxy for gross domestic product (GDP) in urban, developed settings with high prevalence of electricity and street lighting.

Time series of NDVI derived from satellite remote sensing have been used to predict crop yield since the 1980's, with the most common approach being to develop direct empirical relationships between NDVI and yield by generating regression models (van Klompenburg, Kassahun & Catal, 2020; Huang et al., 2013). As the most commonly used vegetation index for crop yield prediction, the availability of studies demonstrating its effectiveness and accuracy far exceeds that of any other vegetation index. The effectiveness of using NDVI to predict crop yield, including for rice, has been demonstrated by numerous studies (dela Torre, Gao and Macinnis-Ng, 2021; Prasad, Singh and

Kafatos, 2007; Huang et al., 2013). For example, a comprehensive research looking at all primary rice-production regions of China from 1982 to 2004 found that the association between the predicted and observed rice crop yield was highly significant, with an overall relative error of only 5.82% (Huang et al., 2013). The accuracy of this approach has been found to be high, often exceeding 80%, across many different studies in different regions worldwide (Zhao, Li & Ma, 2021). For this reason, it remains the best approach in optical remote sensing for crop yield prediction, given the demonstrated applicability in different geographic contexts and reliability (Zhao, Li & Ma, 2021; de Castro et al., 2021).

The literature on remote sensing for disaster applications has recognised that vegetation regrowth and the return to pre-disaster agricultural yields can be used as proxies for post-disaster recovery in areas where agriculture is the dominant livelihood source (Joyce et al., 2009).

In Odisha, twenty years after SC 1999, there is still no study that quantifies differential post-disaster recovery. A central question that remains unanswered is whether some places have recovered quicker than others. Answering this question is challenging due to the lack of recorded baseline data. Cyclones continue to especially adversely impact agricultural production, damaging millions of hectares of cropland, which is by far the main source of livelihoods (Government of Odisha, 2017b), so have crop yield levels returned to pre-disaster conditions, allowing communities to recover their livelihoods? If so, where and how long after the event has this happened?

To fill this gap, this study aims to investigate post-disaster recovery in the study site using crop yield as a proxy measure. It specifically seeks to estimate differential post-disaster recovery rates through time and identify recovery hotspots/coldspots in the case study area. Given that agriculture is the main source of livelihoods and rice represents 90% of the total agricultural production (Government of Odisha, 2011), we argue that rice crop yield can be used as a proxy for post-disaster recovery, whereby recovery is considered achieved when returning to yield values that are at least equal to, if not higher, than pre-disaster baselines. This chapter considers the same villages in the Kendrapara District of Odisha as Chapter 5 as a case study. The following section details the methods used to answer these questions.

## 6.2 Methods

This study uses high-resolution satellite images to derive NDVI, which is utilised to identify correlation with crop yield from official yield data and to then be able to estimate crop yield at higher spatial resolution and for time series for which official records are not available or accessible.

NDVI, closely related to the vegetation greenness, has been used as a proxy measure of crop yield, at the peak of crop development, since the 1980's (Lopresti, Di Bella and Degioanni, 2015).

### 6.2.1 Data sources

#### 6.2.1.1 Crop yield

Official data from the Government of Odisha on annual rice crop yield (in kg/ha) by Block are available for the period 2001-2010. The agricultural crop year in India runs from July to June, with two main seasons based on the monsoon: i) *kharif* from July to October; and ii) *rabi* from October to March (Government of India, 2018a). SC 1999 made landfall in Odisha in October 1999, therefore impacting *kharif* production, whose harvesting period is September-October (ibid.). Crop yield for *kharif* was, thus, considered for this study.

#### 6.2.1.2 Satellite images

Both Moderate Resolution Imaging Spectro-radiometer (MODIS) and Landsat scenes, at a resolution of 500 m and 300 m respectively, were available and used for this study. It was not possible to use satellite images from more recent sensors like Sentinel given the time window of this research dating back to the 1990s.

MODIS satellite images for the period 2001-2010, for which official crop yield data at the Block level were available, were used to determine the statistical correlation between NDVI and crop yield. MODIS Vegetation Indices 16-day L3 Global 500m (MOD13A1) NDVI data are available for download from NASA Earthdata[2] for the study site (Kendrapara District – Lat. 20.5848; Lon. 86.6611).

Landsat scenes were subsequently used to calculate NDVI at the village level over the extended period 1990-2011 and derive village-level crop yield figures using the linear regression model built from MODIS. Landsat 4-5 TM C1 Level-2 and Landsat 7 ETM+ C1 Level-2 scenes, showing surface reflectance, were downloaded from the United States Geological Survey (USGS) Earth Explorer[3].

The advantage of using MODIS for the empirical estimation of the correlation between yield and NDVI is that cloud-free scenes were available for the desired period of time with a relatively higher frequency than Landsat. While the spatial resolution is lower compared to Landsat (500 m versus

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[2] https://earthdata.nasa.gov/
[3] https://earthexplorer.usgs.gov/

30 m), it was deemed sufficient to differentiate between agricultural and non-agricultural areas for the purpose of building the model.

The use of Landsat scenes to then build on results from MODIS to downscale crop yield values officially available at the Block level down to the village level and determine yield for an extended period of time, on the other hand, allowed for higher resolution of the analysis at 30 m while guaranteeing the historical availability of scenes.

The use of multiple optical imagery combining the high temporal but coarse spatial resolution of MODIS with low temporal but high spatial resolution of Landsat has proven effective for NDVI and rice paddy applications in the literature. For example, Ding et al. (2020) were able to achieve an accuracy of over 93% in identifying rice crop regions in southern China from NDVI using a combination of imagery from different sensors (MODIS, Landsat 7 ETM+ and Landsat 8 OLI). Qin et al. (2015) further demonstrated that the combination of Landsat 7 ETM+ and Landsat 8 OLI for rice crop mapping from NDVI improved accuracy by increasing the frequency of observation with greater chances of tracking the phenology. Rice crop areas estimated only from Landsat 7 ETM+ or Landsat 8 OLI were only 81% and 90.9% of those estimated through the fusion of both.

The necessity to combine MODIS and Landsat scenes to be able to access at the same time higher frequency images from MODIS to build the model at the Block level and higher resolution images from Landsat to downscale it to the village level was key to this study and reinforces the selection of NDVI as the spectral index for crop yield prediction given the great availability of studies demonstrating the compatibility of combining imagery from different sensors (including, MODIS and Landsat in particular) and resulting accuracy for NDVI specifically.

Global landcover data were used to differentiate between agricultural and non-agricultural areas when working with NDVI.

#### 6.2.1.3 Landcover

Land cover data were used to differentiate between agricultural and non-agricultural areas. Available data include annual global landcover maps at 300-metre spatial resolution produced by the European Space Agency Climate Change Initiative[4] for the period from 1992 to 2015, as well as

[4] http://cci.esa.int/data

a 2015 landcover map at 30-metre resolution available through the Global Food Security Support Analysis Data (GFSAD30)[5] managed by the United States Geological Survey (USGS).

The European Space Agency Climate Change Initiative also provides an assessment of the overall landcover changes experienced over the entire period of time (1992-2015). When confined to the District of Kendrapara, we see that only 3% of the area (395 pixels out of 12,709) was subject to one landcover change between these years. Figure 6.1 shows the spatial distribution of these changes. The overall accuracy of the European Space Agency Climate Change Initiative landcover maps is found to be between 71.45% and 75.38%, with some of the highest accuracy values for cropland ranging between 80% and 92%. The changes detected over the 1992-2015 period for the District of Kendrapara, thus, appear to be of the same order as the error of classification and, therefore, not significant.

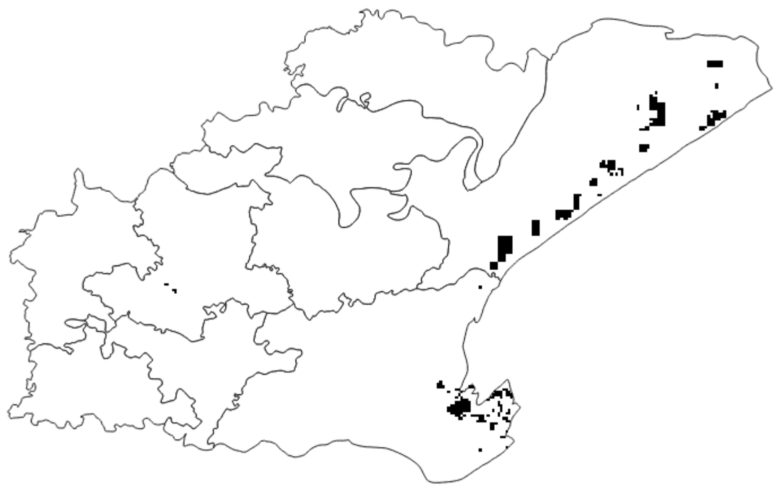

Figure 6.1: Areas that have experienced one landcover change between 1992 and 2015 in the Kendrapara District of Odisha, India (in black)

Furthermore, an analysis of official records of winter rice crop production areas between 2001 and 2011 shows an average annual variation of only 1% across the District of Kendrapara, thus also demonstrating the limited variation in land use for cropland.

In view of the above, the 2015 landcover map from the Global Food Security Support Analysis Data was used in this analysis, assuming limited change over the study period and given its higher resolution (30-metre), which is comparable to that of Landsat scenes considered for the study.

[5] https://www.usgs.gov/centers/wgsc/science/global-food-security-support-analysis-data-30-m

#### 6.2.1.4 Village boundaries

The 2001 'India Village-Level Geospatial Socio-Economic Data Set' retrieved from NASA's Socioeconomic Data and Applications Center (SEDAC)[6], which includes georeferences from the 2001 national census, was used for village boundaries. This study focuses on the same villages that were identified in Chapter 5. Therefore, the village boundary shapefile was restricted to those ones using census codes for identification of villages. The census code comparison between 2001 and 2011 from OpenStreetMap Wiki was used to aid village identification across the two national census[7]. It was not possible to retrieve a limited number of villages; therefore, these were excluded from the analysis. A total of 627 villages were retained.

### 6.2.2 Correlation between crop yield and NDVI

MODIS Vegetation Indices 16-day L3 Global 500m (MOD13A1) NDVI data were used to establish the relationship between rice crop yield and NDVI and identify the period of the year showing best correlation. Available scenes for the months of September and October were downloaded over a five-year timeline, from 2006 to 2010, to find the period of best correlation within the time range considered every year (September to October as the harvesting period).

#### 6.2.2.1 Data processing

The NDVI images have then been scaled to consider MODIS scaling factor of 0.0001, with NDVI values ranging between -1 and +1. Land cover data were subsequently used to differentiate between agricultural and non-agricultural areas. 2015 data were available for the target site through the Global Food Security-Support Analysis Data at 30-metre resolution (GFSAD30) managed by the United States Geological Survey (USGS), which provide high-resolution global cropland data. These were used to create a mask to exclude non-agricultural areas from further analysis, considering only cropland for correlation between crop yield and NDVI (0 value for non-agricultural areas; 1 value for agricultural areas). They were resampled to MODIS resolution of 500 metres using a mode (majority) resampling method, so that the agricultural vs. non-agricultural class was assigned based on the attribute of most pixels in each cell. NDVI values were then multiplied by this binary (0; 1) resampled mask layer to retain only the NDVI for agricultural areas. Mean NDVI values by Block per scene were computed in QGIS.

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[6] https://earthdata.nasa.gov/eosdis/daacs/sedac
[7] https://wiki.openstreetmap.org/wiki/Subdistricts_in_Odisha

#### 6.2.2.2 Linear regression model

A linear regression model was then applied to establish the relationship between NDVI values as the independent variable and crop yield as the dependent variable. Linear regression models have been used in many studies to investigate the correlation between NDVI and yield (Lopresti, Di Bella and Degioanni, 2015).

R squared were computed for each scene (four scenes available for every year). The mean R squared was calculated for each scene period and the best correlation was found for scenes covering the second half of October (mean R squared by scene period equals 0.66).

Table 6.1: Mean R squared by scene period for the years 2006-2010

| | **2006** | **2007** | **2008** | **2009** | **2010** | |
|---|---|---|---|---|---|---|
| **Image date** | **R squared** | **R squared** | **R squared** | **R squared** | **R squared** | **Mean by scene period** |
| 29Aug13Sep | 0.35 | 0.29 | 0.03 | 0.67 | 0.37 | 0.34 |
| 14Sep29Sep | 0.79 | 0.03 | 0.04 | 0.72 | 0.74 | 0.46 |
| 30Sep15Oct | 0.86 | 0.42 | 0.50 | 0.64 | 0.71 | 0.63 |
| 16Oct31Oct | 0.83 | 0.53 | 0.55 | 0.64 | 0.76 | 0.66 |

Subsequently, MODIS scenes within the period from 16$^{th}$ to 31$^{st}$ October of each year were used for the years for which official *kharif* crop yield records are available (2001-2010) to establish the relationship between NDVI and crop yield.

Within the time range from 2001 to 2010, linear regression models were applied to six years and tested on the remaining four years to predict crop yield in an iterative manner. For example, they were applied to the model period 2001-2006 and tested for the test period 2007-2010; then they were subsequently applied to the model period 2002-2007 and tested for the test period 2008-2001; and so on. These were restricted to the range of values observed. The normalized root mean squared error (RMSE) between observed and predicted crop yield was computed to identify the best model. Table 6.2 shows the results. The model with the least RMSE was retained.

Table 6.2: Linear regression models to establish correlation between crop yield and NDVI (in bold, the model with the smallest normalised root mean squared error)

| Model period | Equation (yield=a*NDVI+b) | Test period | Normalised RMSE |
|---|---|---|---|
| 2001-2006 | y = 92,289x - 39,958 | 2007-2010 | 0.2886 |
| 2002-2007 | y = 88,91x - 37,384 | 2008-2001 | 0.2939 |
| 2003-2008 | y = 85,389x - 36,766 | 2009-2002 | 0.3375 |
| 2004-2009 | y = 87,372x - 34,338 | 2010-2003 | 0.3923 |
| **2005-2010** | **y = 84,978x - 33,812** | **2001-2004** | **0.2868** |
| 2006-2001 | y = 108,98x - 50,419 | 2002-2005 | 0.3060 |
| 2007-2002 | y = 112,67x - 53,152 | 2003-2006 | 0.2897 |
| 2008-2003 | y = 115,25x - 55,418 | 2004-2007 | 0.2984 |
| 2009-2004 | y = 126,68x -63,212 | 2005-2008 | 0.3786 |
| 2010-2005 | y = 86,807x - 36,535 | 2006-2009 | 0.2934 |

### 6.2.3 Estimation of crop yield at village level

Landsat 4-5 TM C1 Level-2 and Landsat 7 ETM+ C1 Level-2 scenes were used to calculate mean NDVI by village over the period 1990-2011. The linear regression model built from MODIS was then applied to derive crop yield at the village scale.

#### 6.2.3.1 Data processing

Landsat 4-5 TM C1 Level-2 and Landsat 7 ETM+ C1 Level-2 scenes, showing surface reflectance, were downloaded from the United States Geological Survey (USGS) Earth Explorer[8]. A total of 47 Landsat 4-5 TM C1 Level-2 and 33 Landsat 7 ETM+ C1 Level-2 scenes were available for the period of September-October 1990-2018.

From the correlation analysis of MODIS NDVI and crop yield, we know that the best correlation is found between 16$^{th}$ and 31$^{st}$ October. The second highest correlation is found for the period from 30$^{th}$ September to 15$^{th}$ October. Therefore, all cloud-free scenes falling in the period of highest correlation were retained. When cloud-free scenes were not available for the highest correlation period of a particular year but were available for the second-best correlation period, these were retained. Finally, when cloud-free scenes were not available for either of those high correlation periods but were available for the months considered, those closest to the desired dates were also retained.

Overall, Landsat 4-5 TM C1 Level-2 cloud-free scenes were available for the following years: 1990-1994, 1996-1997, 2004-2009, and 2011. In addition, Landsat 7 ETM+ C1 Level-2 were available for

[8] https://earthexplorer.usgs.gov/

the following years: 2000-2002, 2004, 2006-2018. Finally, Landsat 8 OLI/TIRS C1 Level-2 scenes were available for the period 2013-2018.

Noting that, according to USGS (USGS, 2017), Landsat 7 scenes collected starting from 31st May 2003 have only 78% of their pixels and consequent data gaps, only available Landsat 7 scenes before 2003, which had scan line correction, were used. In line with the focus period of this study, images between 1990 and 2011 were considered.

The following scenes were retained:

Table 6.3: Retained Landsat scenes

| **Satellite** | **Year** | **Day/month** |
|---|---|---|
| Landsat 4-5 TM C1 Level-2 | 1990 | 20 October |
| Landsat 4-5 TM C1 Level-2 | 1991 | 23 October |
| Landsat 4-5 TM C1 Level-2 | 1992 | 25 October |
| Landsat 4-5 TM C1 Level-2 | 1993 | 28 October |
| Landsat 4-5 TM C1 Level-2 | 1994 | 31 October |
| Landsat 4-5 TM C1 Level-2 | 1996 | 20 October |
| Landsat 4-5 TM C1 Level-2 | 1997 | 7 October |
| Landsat 7 ETM+ C1 Level-2 | 2000 | 23 October |
| Landsat 7 ETM+ C1 Level-2 | 2001 | 26 October |
| Landsat 7 ETM+ C1 Level-2 | 2002 | 29 October |
| Landsat 4-5 TM C1 Level-2 | 2004 | 26 October |
| Landsat 4-5 TM C1 Level-2 | 2005 | 13 October |
| Landsat 4-5 TM C1 Level-2 | 2006 | 16 October |
| Landsat 4-5 TM C1 Level-2 | 2007 | 3 October |
| Landsat 4-5 TM C1 Level-2 | 2008 | 21 October |
| Landsat 4-5 TM C1 Level-2 | 2009 | 24 October |
| Landsat 4-5 TM C1 Level-2 | 2011 | 28 September |

#### 6.2.3.2 Mean NDVI calculation by village

The retained Landsat scenes were processed to calculate NDVI and subsequently use the regression model built from MODIS satellite images to estimate crop yield by village.

NDVI can be calculated from surface reflectance as the ratio between red (R) and near infrared (NIR) values (USGS, 2017):

$$(NIR - R) / (NIR + R)$$

The scenes were cloud masked using Landsat Quality Assurance and NDVI was computed in QGIS using the following the equation for Landsat 4-7 (USGS, 2017):

$$NDVI = (Band\ 4 – Band\ 3) / (Band\ 4 + Band\ 3)$$

Land cover data were subsequently used to differentiate between agricultural and non-agricultural areas. 2015 data were available for the target site through the Global Food Security-Support Analysis Data at 30-metre resolution (GFSAD30) managed by the United States Geological Survey (USGS), which provide high-resolution global cropland data. These were used to create a mask to exclude non-agricultural areas from further analysis, considering only cropland for correlation between crop yield and NDVI (0 value for non-agricultural areas; 1 value for agricultural areas). Noting that the resolution of these landcover data is the same as that of Landsat 4-7 scenes, no resampling was needed. NDVI values were then multiplied by this binary (0; 1) resampled mask layer to retain only the NDVI for agricultural areas. Mean NDVI values by village per scene were computed in QGIS.

#### 6.2.3.3 Linear regression model application

The linear regression model built from MODIS was then applied to estimate crop yield from NDVI for the years 1990-2011 at the village scale.

## 6.3 Results

### 6.3.1 Recovery hotspot/coldspot mapping

Crop yield by village by year was plotted for all 627 villages for the period 1990-2011 (Figure 6.2). No data were available for the years 1995, 1998-1999, 2003 and 2007; therefore, these are shown as data gaps.

SC 1999 falls in the data gap period of 1998-1999. To understand variations in crop yield before and after the event, two periods of equal duration (for statistical significance) before 1997 and after 1999 were considered: 1991-1997 and 2000-2006. Both these periods present one year as a data gap. The period 1991-19997 was used to represent baseline conditions, whereas the period 2000-2006 represents post-disaster conditions. The mean, trendline and standard deviation error bars of crop yield across all 627 villages were computed over these two periods and are plotted in Figures 6.3 and 6.4.

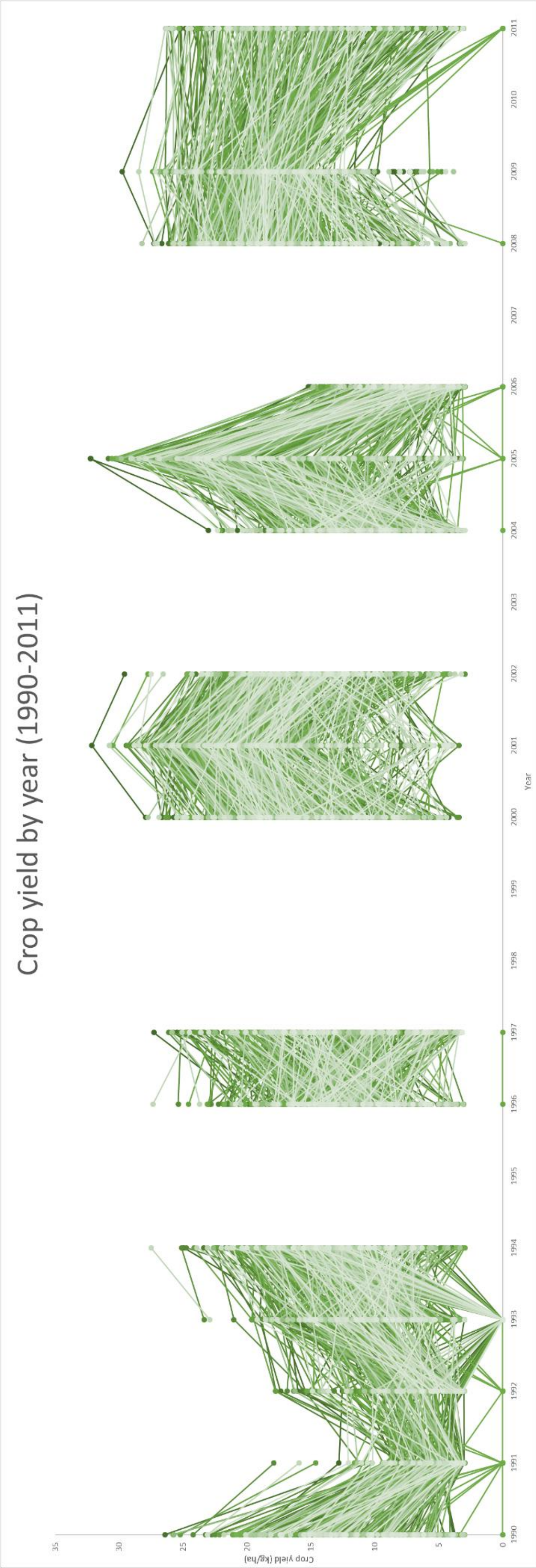
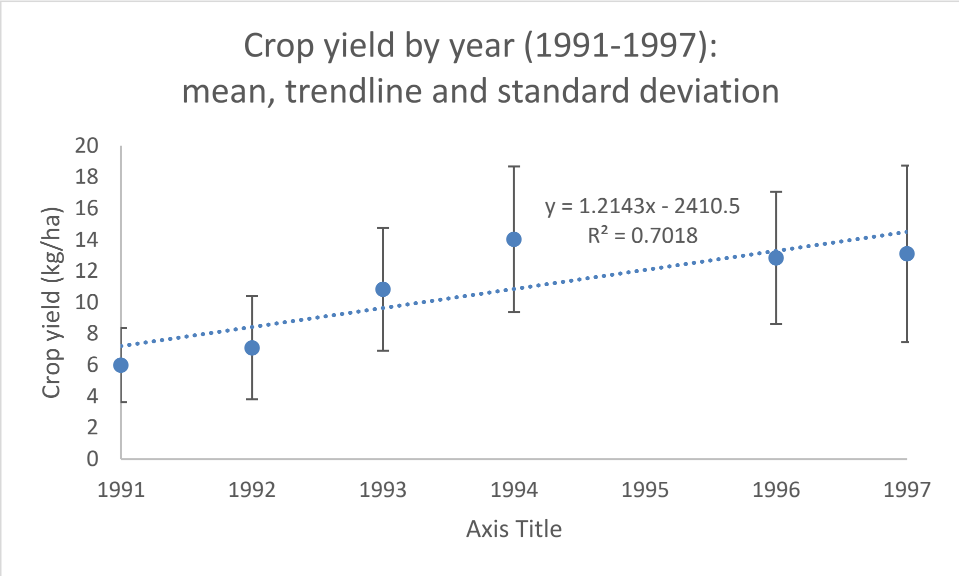



Figure 6.2: Crop yield by village by year (1990-2011)



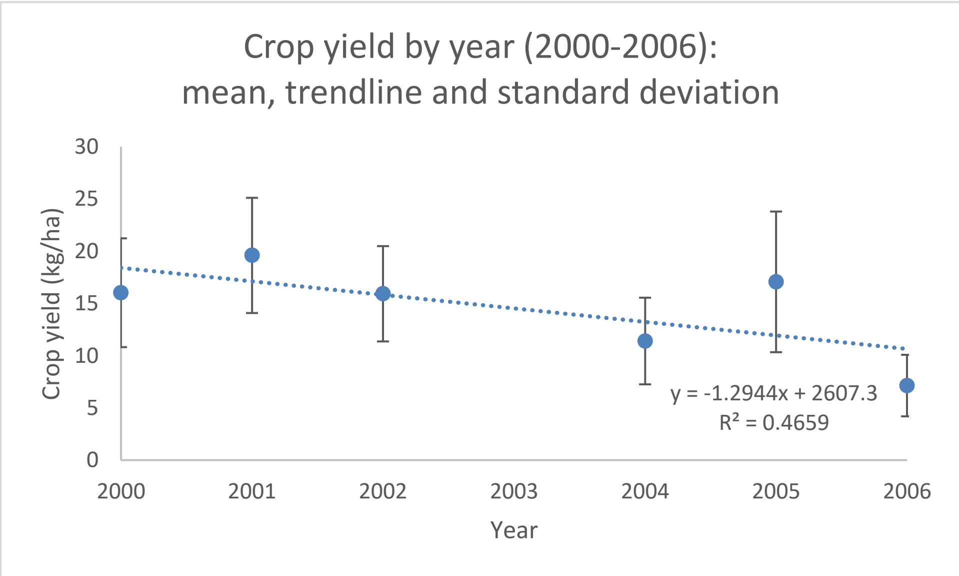




Figure 6.3 (above) and 6.4 (below): Mean, trendline and standard deviation error bars of crop yield by year for the periods 1991-1997 (above) and 2000-2006 (below)

Results show a declining trend ($R^2 = 0.5$) of crop yield over the period 2000-2006, as opposed to an increasing trend ($R^2 = 0.7$) over the period 1991-1997 (Figures 6.3 and 6.4). However, the years immediately after the event (2000-2001) feature a peak in crop yield above pre-disaster conditions (Figures 6.3 and 6.4). These then drop in subsequent years, showing an overall declining trend (Figures 6.3 and 6.4). The initial peak after SC 1999 might be explained by actions taken in the post-disaster phase for early recovery and rehabilitation, including the distribution and use of subsidises fertilisers and climate-resistant seeds. However, this peak is not sustained over the following years when shifting towards the longer-term recovery phase.

Mean crop yield by village from 1991 to 1997 and from 2000 to 2006 were computed. For each village, the 1991-1997 mean was compared with the 2000-2006 mean to understand whether this experienced an increase, a decrease or no change. Out of 627 villages, 567 presented higher mean crop yield values over the period 2000-2006 than those of 1991-1997, with only 56 villages experiencing worsened mean conditions. Despite the declining trend, these villages appear to have recovered from the event. The spatial distribution of these recovery hotspots and coldspots is provided in Figure 6.5. Villages that have not experienced recovery appear to be dispersed.

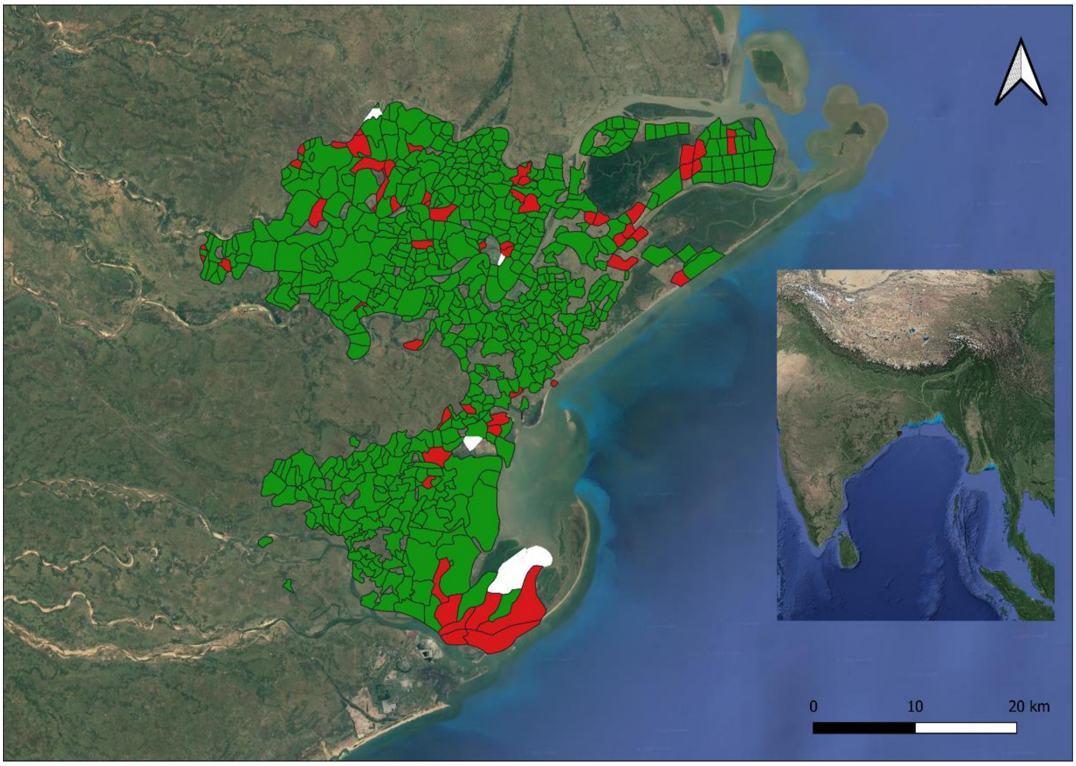



Figure 6.5: Recovery status considering the period 2000-2006 (in green, villages which have recovered to at least 1991-1997 crop yield values; in red, villages that did not recover)

To capture any declining trend, mean crop yield over two-year intervals was computed for each village. When comparing mean crop yield for 2000-2001 with that of 1996-1997, 537 villages experienced a higher yield in post-event conditions. However, this figure significantly drops when moving towards the two-year interval of 2004-2005: only 389 villages experienced a higher 2004-2005 mean crop yield than the 1996-1997 mean crop yield, with 208 villages worst off in 2004-2005 than in 1996-1997. Finally, over the two-year interval of 2008-2009, most villages (527 versus 76) return to experience increased mean crop yield than in 1996-1997.

The spatial distribution of these recovery hotspots and coldspots is provided in Figures 6.6, 6.7 and 6.8. The recovery status as of 2000-2001 shows that coastal communities were better off. This may hint at assistance received in the aftermath of the event, since coastal areas were the main target of relief and early recovery efforts given they were worst impacted (Chittibabu, Dube, MacNabb, et al., 2004; Government of Orissa, 1999).

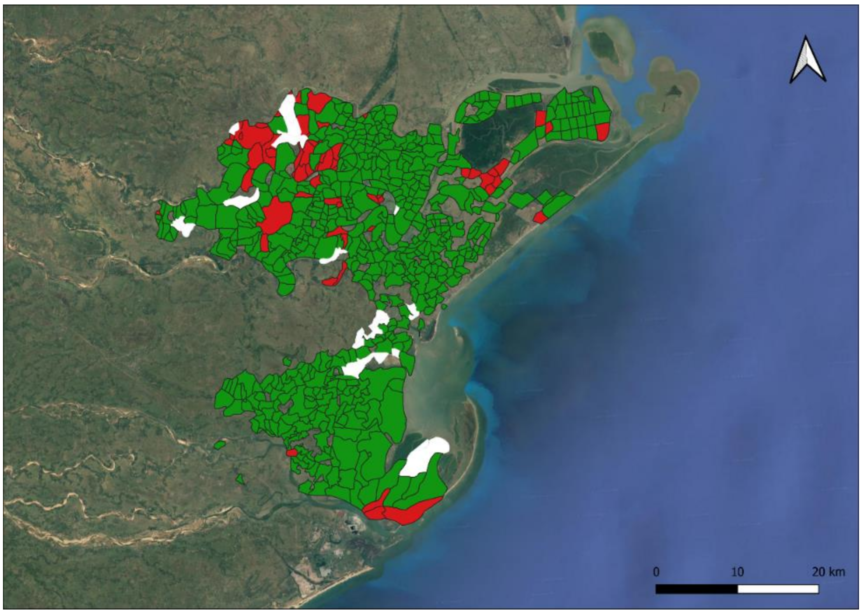



Figure 6.6: Recovery status as of 2000-2001 (in green, villages which have recovered to at least 1996-1997 crop yield values; in red, villages that did not recover)

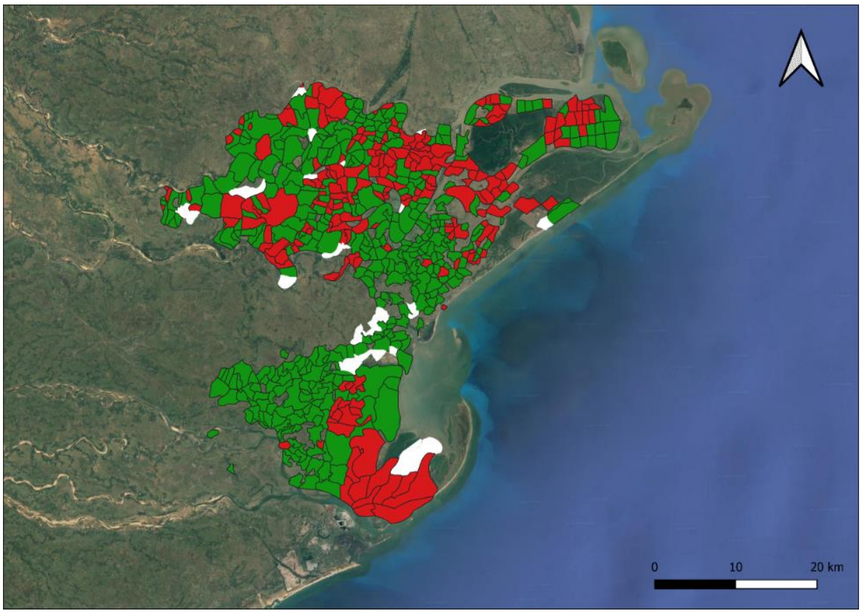



Figure 6.7: Recovery status as of 2004-2005 (in green, villages which have recovered to at least 1996-1997 crop yield values; in red, villages that did not recover)

This thesis considers the cumulated impact of SC 1999 in the face of any other subsequent natural hazards in the study area. The 2004-2005 figures might, thus, be explained by the impact of subsequent disaster events. In 2003, Odisha experienced large-scale floods (Beura, 2015; IFRC, 2003), which are likely to have impacted agricultural production during the following years and may explain these figures. Recovery coldspots (i.e., those which did not recover) appear to be spatially distributed along the coast and riverine areas.

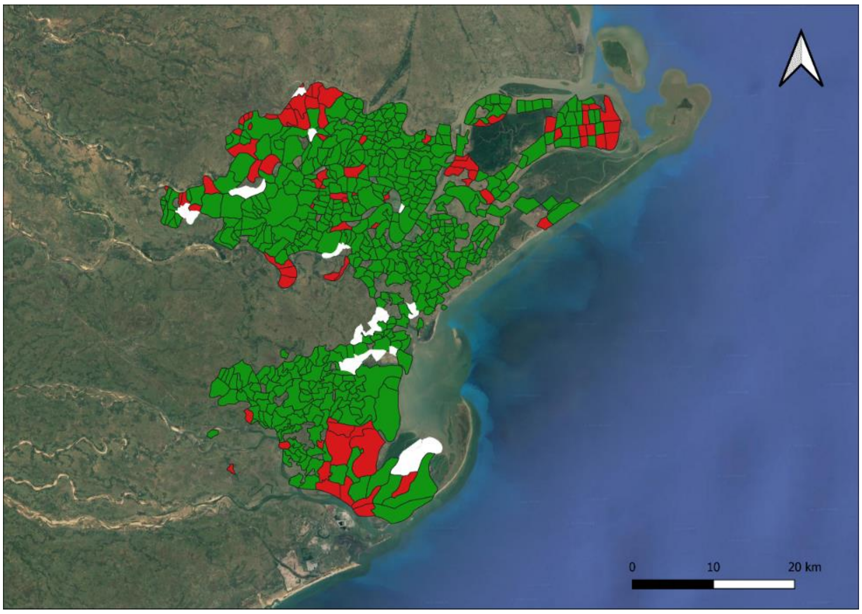



Figure 6.8: Recovery status as of 2008-2009 (in green, villages which have recovered to at least 1996-1997 crop yield values; in red, villages that did not recover)

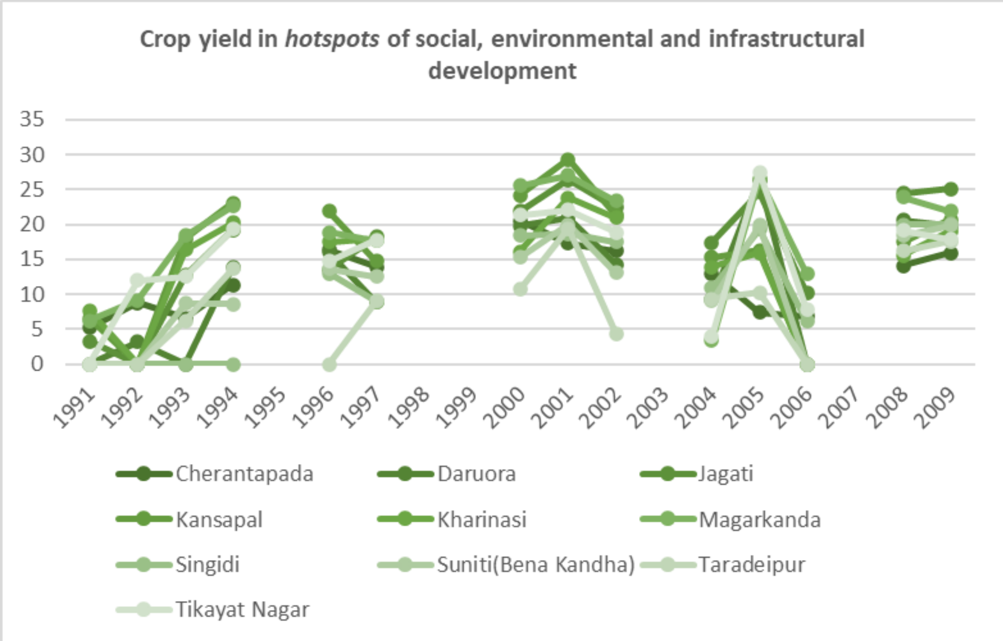
Spatial patters of recovery as of 2008-2009 seem to be in line with those experienced overall over the period 2000-2006.

While most of the villages seems to have recovered to post-disaster conditions at least equal to pre-disaster conditions, there appears to be an overall declining trend, which may hint to long-term effects that might hamper future economic stability in the face of continued exposure to natural hazards.

### 6.3.2 Post-disaster recovery in socio-economic, environmental and infrastructural development hotspots/coldspots

When zooming in on the villages that were identified as socio-economic, environmental and infrastructural development hotspots in chapter 5 (cf. Table 5.3), it is interesting to note they are also experiencing pre-disaster increasing and post-disaster decreasing trends like the average village, with similar statistical significance (Figure 6.10). A similar pattern of an initial bounce in

2000-2001 followed by a reduction in 2004-2005 and subsequent rebounce in 2008-2009, as for the average village overall, is also experienced (Figures 6.9 and 6.11).



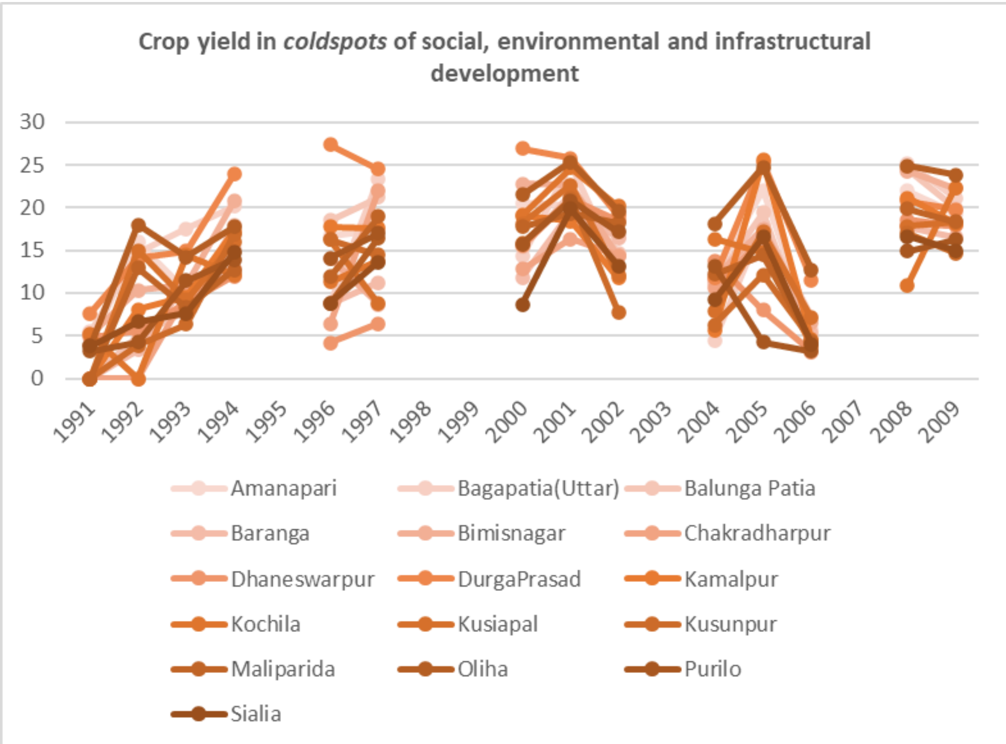
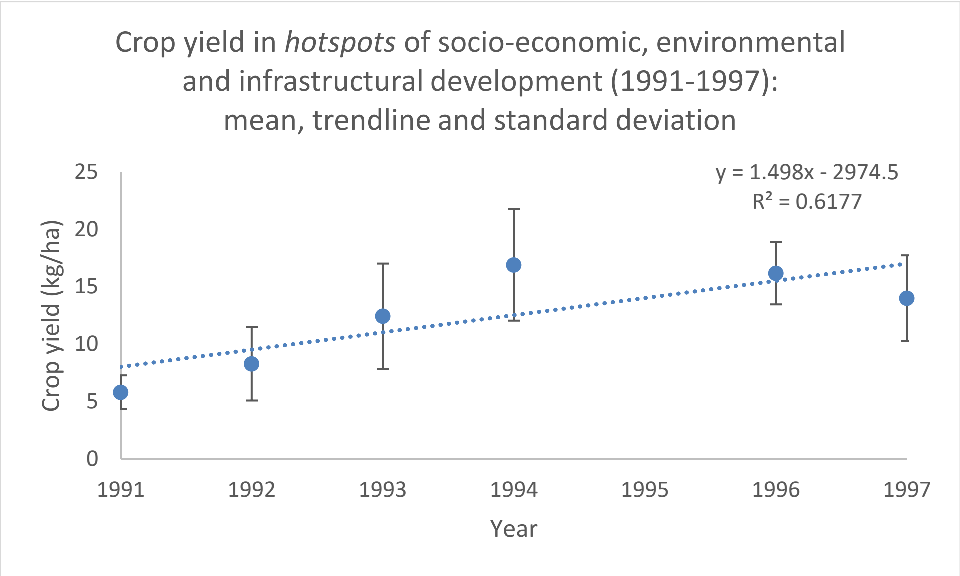




Figure 6.9: Crop yield by village by year (1991-2009) for hotspots of positive socio-economic, environmental and infrastructural development change (above) and coldspots of negative socio-economic, environmental and infrastructural development change (below)



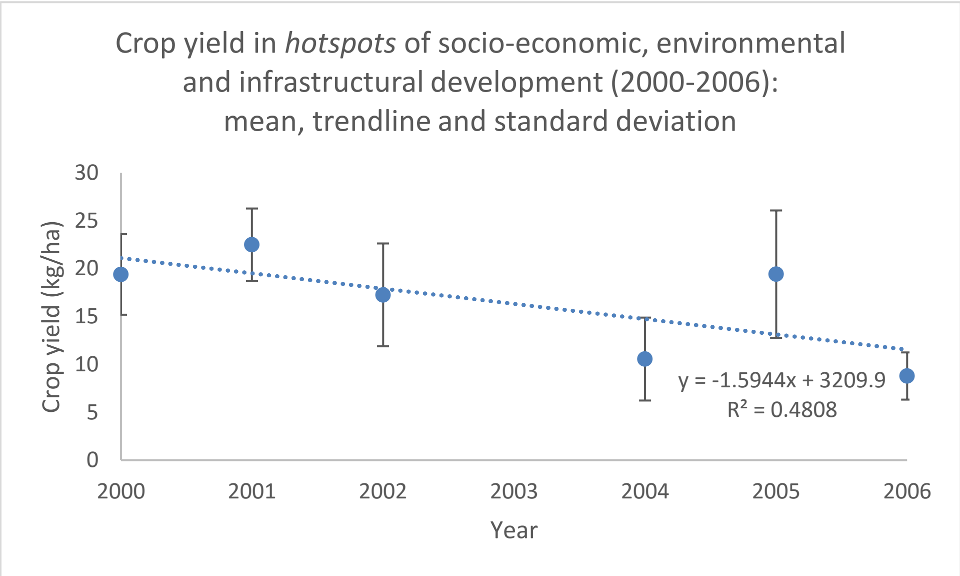




Figure 6.10: Mean, trendline and standard deviation error bars of crop yield by year for the periods 1991-1997 (above) and 2000-2006 (below) for the hotspots of positive socio-economic, environmental and infrastructural development

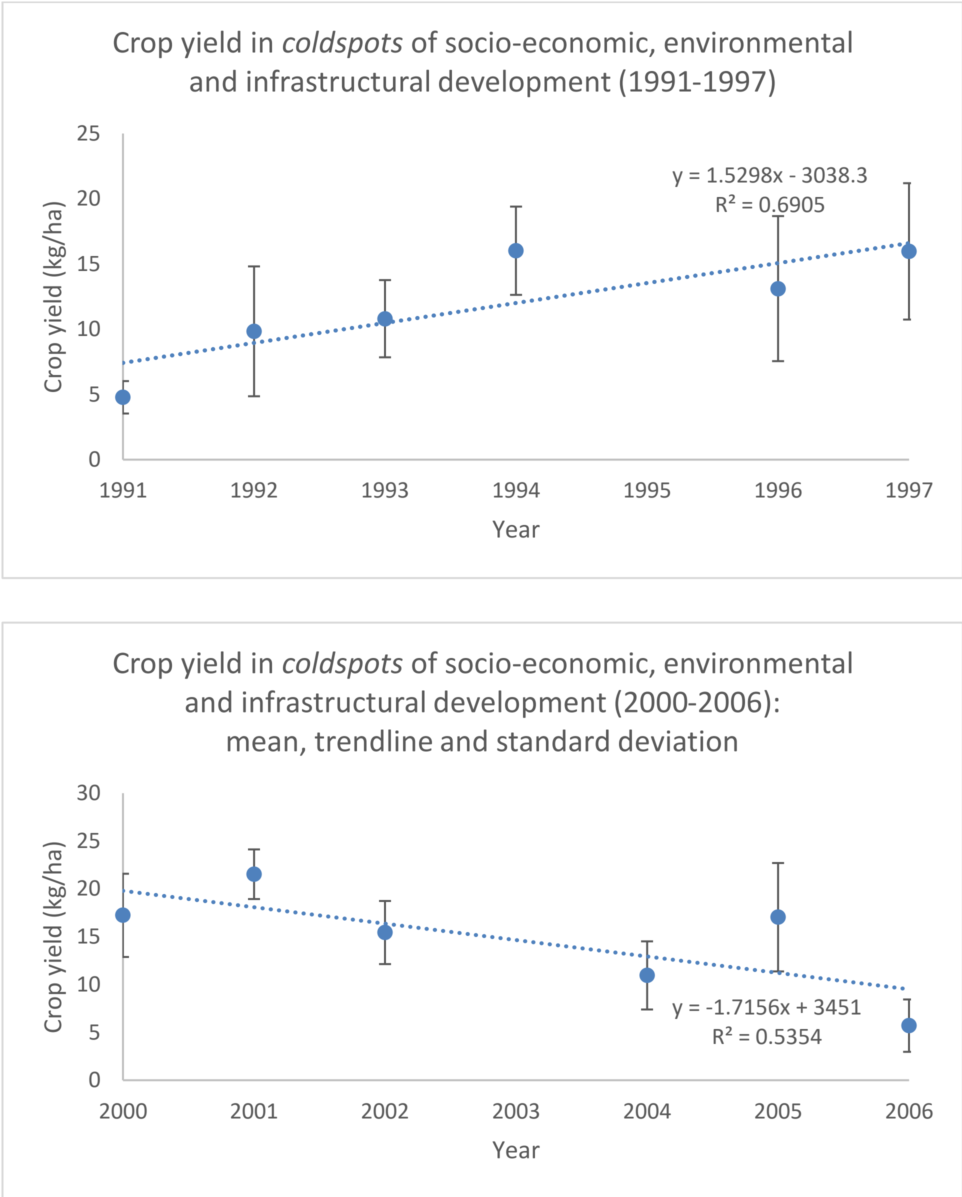



Figure 6.11: Mean, trendline and standard deviation error bars of crop yield by year for the periods 1991-1997 (above) and 2000-2006 (below) for the coldspots of negative socio-economic, environmental and infrastructural development

However, when comparing mean crop yield during the period 1991-1997 (considered as pre-disaster baseline) with mean crop yield during the period 2000-2006 (considered as post-disaster conditions), the villages that were identified as hotspots of positive socio-economic, infrastructural and environmental change show that they have bounced forward, with the 2000-2006 mean crop yield equivalent to 131% of the 1991-1997 mean crop yield (Table 6.4). On the contrary, the villages that were identified as coldspots of negative socio-economic infrastructural and environmental change did not recover, with the 2000-2006 mean crop yield only equivalent to 99% of the 1991-1997 mean crop yield (Table 6.4).

Table 6.4: mean crop yield and variation compared to pre-disaster baseline for hotspots and coldspots of socio-economic, environmental and infrastructural development

| **Hotspots** | | |
|---|---|---|
| **Years** | **Mean crop yield (kg/ha)** | **% of pre-disaster baseline** |
| 1991-1997 | 12.94 | 100% |
| 2000-2006 | 16.98 | 131% |
| **Years** | **Mean crop yield (kg/ha)** | **% of pre-disaster baseline** |
| 1996-1997 | 14.73 | 100% |
| 2000-2001 | 20.94 | 142% |
| 2004-2005 | 14.99 | 102% |
| 2008-2009 | 19.38 | 132% |
| **Coldspots** | | |
| **Years** | **Mean crop yield (kg/ha)** | **% of pre-disaster baseline** |
| 1991-1997 | 12.36 | 100% |
| 2000-2006 | 12.28 | 99% |
| **Years** | **Mean crop yield (kg/ha)** | **% of pre-disaster baseline** |
| 1996-1997 | 14.54 | 100% |
| 2000-2001 | 19.38 | 133% |
| 2004-2005 | 14.00 | 96% |
| 2008-2009 | 19.24 | 132% |

Overall, the hotspots of positive change bounced forward compared to the pre-disaster baseline in all data points considered, with the 2000-2001 mean crop yield equivalent to 142% of the 1991-1997 mean crop yield, the 2004-2005 mean crop yield equivalent to 102% of the 1991-1997 mean crop yield and the 2008-2009 mean crop yield equivalent to 132% of the 1991-1997 mean crop yield (Table 6.4).

On the other hand, the coldspots of negative change initially bounced forward with the 2000-2001 mean crop yield equivalent to 133% of the 1991-1997 mean crop yield, but then bounced back to only 96% of the 1991-1997 mean crop yield, before bouncing forward again to 131% of the 1991-1997 mean crop yield in 2008-2009.

This shows that the hotspots of positive change bounced forward faster than the coldspots of negative change.

## 6.4 Discussion

The availability of high-frequency and high-resolution satellite remote sensing information has paved the way for endless applications to disaster management studies, including for events that have been understudied in the past due to lack of official records, such as SC 1999 (Joyce et al., 2009). Big data and new technologies can support the scale-up of national monitoring and reporting systems, from time- and money-intensive traditional approaches for data collection exclusively relying on national census and surveys to low-cost, open-access, higher-frequency and more localised remote sensing solutions that can help to strengthen accountability, enhance transparency and ultimately reach all those in need (United Nations, 2014). The data revolution can effectively support the implementation of the 2030 global agenda, ensuring that interventions are targeted based on needs and that no one is left behind (United Nations, 2015c).

As demonstrated in this piece of research, satellite remote sensing can answer central questions that have remained unanswered for years, such as how long it took to recover from a specific disaster event like SC 1999 in the face of subsequent natural hazards and which communities may have been left behind in this process.

In areas where agriculture is the dominant livelihood activity employing over half of the total workforce (Government of Odisha, 2017b), crop yield is a fundamental element of post-disaster recovery and can be used as a proxy measure to understand recovery patterns (Ghaffarian et al., 2018; Sustainable Development Solutions Network, 2015; UNISDR, 2018). While many studies have used satellite remote sensing to investigate spatial and temporal changes for different applications, Ghaffarian et al. (2018) found that there are relatively few studies using remote sensing proxies for post-disaster recovery assessment, with most research focusing on post-disaster damage assessment. The same authors also found that, while crops have been mapped as a proxy for recovery, there is little literature actually applying this in practice to investigate long-term post-disaster recovery patters using agricultural production as a key variable (ibid.), with most studies focusing on short-term impact assessment (cf. Blanc & Strobl, 2016; Matsuda, 2012; Stone, 2009). This is also true for Odisha: Haldar et al. (2016), for instance, mapped short-term impacts of cyclone Phailin on rice fields to understand which areas were flooded, but no research has been previously conducted to look at long-term recovery from SC 1999.

The methodology developed here can help in screening differential post-disaster recovery from freely available satellite images to understand whether recovery has occurred and whether there are areas of stagnation and longer-term effects that persist and will require targeted interventions. It has the potential for replication in other areas of the world where the primary sector is the main source of livelihoods and it is especially beneficial for application in developing countries facing severe limitations on data availability (Devarajan, 2013).

Four main findings arise from this study: i) most of the villages considered in this study experienced post-disaster (2000-2006) mean rice crop yield rates at least equivalent to pre-disaster mean baseline rates (1991-1997); ii) there is, however, a declining trend in rice crop yield in years subsequent to SC 1999 as opposed to an increasing trend in years before SC 1999; iii) crop yield rates have further dropped in the face of subsequent natural hazards, hampering any recovery that might have been previously achieved; and iv) villages that have experienced socio-economic, infrastructural and environmental development gains have bounced back and forward faster than villages that have experienced development losses during the study period.

Other studies have found that cyclones can post-disaster harvest rates can either be lower or higher than pre-disaster baselines, depending on the magnitude of the event, the stage in crop development and on post-disaster interventions to support early recovery (Lansigan, De Los Santos, & Coladilla, 2000). For example, Stone (2009) found that rice production had already rebounded one year after cyclone Nargis in Myanmar thanks to the use of high-yield crop varieties. This is in line with findings from Matsuda (2012), which also show, however, that government assistance was still playing a fundamental role three years after Nargis, when the research was conducted. This highlights that cyclones can have long-term adverse effects on agriculture, rural livelihoods and food security, as demonstrated by Duncan et al. (2017) for Odisha. Cyclones may induce changes in the type of crop varieties grown (e.g., to shift towards climate-resistant and/or high-yield varieties) and create dependence on external assistance for long periods of time (Matsuda, 2012). It also points to the potential for studies like this one to support in screening agricultural production changes to understand which areas have been left behind and whether targeted interventions prove to be effective or not (J. M. A. Duncan, Dash, & Atkinson, 2015).

Despite recovering mean crop yields back to at least equivalent pre-disaster rates, this study finds a declining trend in crop yield after SC 1999, in spite of an increasing trend before the calamity. This is the first time this has been proven in the study site. Longer-term trends in post-disaster recovery remain understudied (J. M. A. Duncan et al., 2015; Ghaffarian et al., 2018). Despite the penury of studies looking at long-term post-disaster agricultural patterns, the correlation between climate variables, natural hazards and rice yields has been demonstrated (Sarker, Alam, & Gow, 2012). Understanding trends and patterns is pivotal to further elucidate how to mute the adverse impacts of cyclones to the extent possible (ibid.).

Findings from this study also show that crop yield has dropped below pre-disaster baseline rates over the period 2004-2005, which may be connected to the 2003 floods. While this thesis has focused on the recovery from SC 1999 in the face of any subsequent natural hazard, further research could look into cascading impacts of multiple hazards to further refine the analysis.

Finally, the research provides evidence of faster recovery to improved pre-disaster crop yield baseline conditions in communities that have experienced socio-economic, environmental and infrastructural development gains as opposed to those that have experienced development losses.

This demonstrates the huge potential that lies in using satellite remote sensing to monitor and predict social change and outcomes in the context of development and disasters, providing a contribution to the literature on the nexus (see chapter 2, section 2.5). It proves that low-cost, mixed methods approaches combining statistical analysis of national census data with satellite earth observation can be used for large-scale studies to overcome limitations in data availability, in line with literature on the topic (Watmough, Atkinson & Hutton, 2013a; Sustainable Development Solutions Network, 2015), while showing applicability for post-disaster recovery analysis (Joyce et al., 2009).

It will be interesting for future research to extend the timeline by looking at the subsequent decade too as 2021 census data becomes available or through projections to see how the cyclone-affected areas are positioned in relation to the economic development experienced on average within the state since 2004-2005 (see chapter 2, section 2.6.2) thanks to a shift towards other economic sectors less exposed to natural hazards than agriculture, when Odisha's Net State Domestic Product (NSDP) began to rise again, reversing what had been a declining trend with respect to national levels for many years, equalling 90% of the country's average in fiscal year 1950-1951 down to 61% of the country's average in 2002-2003 (Government of Odisha, 2011).

In conclusion, this study demonstrates the potential of satellite remote sensing to map long-term post-disaster agricultural recovery to understand whether recovery has occurred and, if so, where and how long after a disaster. In doing so, it can help assess which areas may have been left behind in the process of recovery and inform practical and policy interventions accordingly.

With an increasing amount of volunteered georeferenced information and enhanced engagement of citizens in crowdsourcing and data mining initiatives (cf. OpenStreetMap, MapAction and Missing Maps, among others), there is potential for replication in disaster-prone areas all over the world at little to no cost (Antoniou, 2018; Haklay, 2013). Furthermore, with increased access to smartphones and internet in rural communities, methods like this one can support and benefit from digital agriculture initiatives, such as Agriculture 2.0 in India (Government of India, 2018b), developed to enhance information sharing with farmers. Crowdsourcing contributes to bottom-up generation of data and can complement, refine and verify remote sensing data for ground-truthing (Fava, Jensen, Oto, & Mude, 2018; Fritz et al., 2009; H. Li, Yang, & Zeng, 2018; Schepaschenko et al., 2015). By doing so, it can effectively support in stepping up monitoring efforts to more effectively respond to disasters and to ultimately achieve global goals and targets (Antoniou, 2018).

This study only considers crop yield. This is a limitation that further research could address to investigate changes in other features of crop production which have been proven to also be influenced by weather-related hazards (Iizumi & Ramankutty, 2015). This notably includes the extent of cropping area (e.g., changes in arable land due to salinity intrusion and other factors directly associated with cyclones) and cropping intensity as it relates to multiple cropping seasons during a year (i.e., extending the study to *rabi*) (ibid.).

## 6.5 Conclusion

In the face of a climate emergency, we are confronted with unprecedented challenges which will require transformational change to meet them while leaving no one behind (IPCC, 2018; United Nations, 2015c). The 2030 agenda and the Sendai Framework set ambitious global goals and targets. Monitoring and reporting on progress is fundamental towards their achievement (UNISDR, 2018; United Nations, 2017). National monitoring systems, however, appear to be outdated to effectively capture change in rapidly evolving situations (Jacob, 2017; United Nations, 2014). There is an urgency to step up monitoring and reporting efforts to ensure that actions are targeted to those in need, monitored and evaluated (Jacob, 2017; United Nations, 2014).

At the same time, we have access to more data than ever before. Big data and new technologies offer unprecedented ways to generate knowledge from data in a faster, finer and border-free manner (United Nations, 2014). Satellite remote sensing has emerged as a key contribution to monitoring efforts, with valuable applications for the field of disaster risk management (Joyce et al., 2009). Its utilisation for post-disaster recovery assessment has, however, been limited so far, with most studies focusing on short-term damage assessment and recovery remaining an understudied phase of disaster risk management (Aldrich, 2016; Cretney, 2017; Ghaffarian et al., 2018; G. Smith et al., 2018).

Twenty years after SC 1999 brought devastation to Odisha, India, there is still no understanding of post-disaster recovery patterns. With agriculture as the main source of livelihoods, no research has previously attempted to investigate long-term crop yield recovery.

This study addressed this gap by looking at recovery trends and patterns over the period 1990-2011. It found that crop yield returned to rates like those before the cyclone in most of the villages studies. However, crop yield proved to be on a declining trend after SC 1999, as opposed to a rising trend before the cyclone. Safety nets and the assistance provided in the aftermath of the event are likely to have played a role in early recovery, as demonstrated by high yield rates in the years 2000-

2001 immediately after the event. Recovery was also found to experience highs and lows in the aftermath of the event, with lows possibly attributable to subsequent natural hazards impacting the area such as the 2003 floods. Finally, it was found that villages that had experienced positive socio-economic, infrastructural and environmental development changes recovered faster than those that experienced negative development changes, which demonstrates the effectiveness of using proxy measures derived from satellite earth observation for characterising the spatial distribution of post-disaster recovery at large scale in data-poor contexts.

# Chapter 7: Community perceptions of development gains and losses and their relation with post-disaster recovery in the Kendrapara District of Odisha, India

## 7.1 Introduction

This chapter aims to compare and contrast community perceptions of socio-economic, environmental and infrastructural development changes and their implications for post-disaster recovery (research objective 4). The relationship between disasters and development has been largely debated (Albala-Bertrand, 1993, 2013; A.E. Collins, 2009; Mochizuki et al., 2014b). This remains at the forefront of the global agenda, with sustainable development being increasingly associated with disaster risk reduction (A.E. Collins, 2013). In line with this, the 2019 Global Assessment Report (UNISDR, 2019) recognises that, in the face of a changing climate, disasters can threaten all pillars of sustainable development, notably its social, environmental and economic dimensions. It also highlights that human activity can trigger small changes which can be amplified by dependent and cascading effects. This reflects the Sendai Framework for Disaster Risk Reduction 2015-2030's goal to reduce disaster risk by implementing 'integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures' (UNISDR, 2015b).

In spite of this, most applied studies on the linkages between disasters and development have been sectorial (A.E. Collins, 2013) and predominantly theoretical or qualitative (Mochizuki et al., 2014b), while further research is needed to investigate the relationship between disasters and increasingly complex socio-economic and environmental change (A.E. Collins, 2013), with significant gaps in quantitative evidence of this relationship (Mochizuki et al., 2014b). Overall, existing analytical work has predominantly focussed on the macro-level, looking at global changes and/or applications to national contexts, or on the micro-level, at the household and/or individual scale, with highly contextualised results that offer limited capacity for replication elsewhere (Barakat, Pelling, & Ozerdem, 2002; Mochizuki et al., 2014b). There appears to be a gap in meso-level research that can help in bridging macro- and micro-levels by investigating the relationship between disasters and development at the community and/or village level using representative samples to understand systemic change (Greene & Greene, 2009).

When it comes to the disaster risk management cycle, post-disaster recovery remains one of the least studied phases (Berke et al., 1993; Nakagawa & Shaw, 2004; Quarantelli, 1999; G. Smith et al., 2018; G. P. Smith & Wenger, 2007). In particular, there is a lack of evidence of how socio-economic, environmental and infrastructural development can be an enabling or disabling factor for recovery in the aftermath of a disaster in the long run (G. Smith et al., 2018). While frameworks for disaster recovery assessment exists, they have been criticised for relying on development indicators with no clear indication of the mutual interrelation between the two, as well for being predominantly expert-driven with no consideration of community perceptions (Weichselgartner & Kelman, 2015).

Against this background, this research study adopts a development-oriented approach to recovery that uses ground information gathered through participatory approaches to inform the methodological design, then analyses past quantitative data to identify development changes with their associates and further investigates these factors and their mutual interactions on the ground with local communities to understand how they are perceived to impact recovery from natural hazards as a means of verification.

Results from a data-driven analysis of past development gains and losses in a selected area of interest, i.e. the Kendrapara District of Odisha, using census data provided interesting highlights on the major associates of socio-economic, environmental and infrastructural development over a ten-year study period, from 2001 to 2011. The analysis showed that these factors most notably pertain to the spheres of communication, infrastructure, gender and vulnerable groups and contributed to gathering some preliminary evidence of key agents for development in the study place.

While this quantitative study contributes to providing a data-informed, objective assessment of the main areas of change occurred during the study period, the restriction of the research domain to available data as well as issues on data reliability and accessibility represent major limitations to the analysis.

Such shortcomings of purely quantitative assessments can be overcome by integrating and complementing this information with qualitative research conducted on field to understand what has not been captured from available data (cf. Dauphiné, 2004; Weichselgartner & Kelman, 2015; Kelman, Gaillard, & Mercier, 2015), as well as to gather further evidence of the interactions between these and other agents of development and their impact on post-disaster recovery.

Mixed methods approaches have been praised for effectively combining the need to provide measurable elements useful for impact evaluation with qualitative findings on issues that cannot be quantifiable or properly emerge from quantitative research (Berchoux & Hutton, 2019; Barrett & Constas, 2014; Cardona, 2003).

A growing body of literature has been looking at applying mixed methods approaches to characterise the relationship between poverty and the environment. For example, research in the same study area has proven effective at integrating local knowledge gathered from Participatory Rural Appraisals into quantitative analysis from population surveys and remote sensing to characterise rural livelihoods (Berchoux & Hutton, 2019).

While the use of a mixed, quantitative and qualitative, approach adds a dimension of subjectivity to the study, it has been suggested in literature that looking at objectivity as the metrics for reliable assessments in a field such as that of post-disaster recovery where there is still little agreement on the theory behind it and its practical implications may not be a realistic approach (Kelman, Gaillard, & Mercier, 2015).

For this reason, qualitative methods were used to explore how community perceptions of development relate to quantitative evidence and to investigate the relation between development and post-disaster recovery as perceived by locals.

Community perceptions were integrated in two ways in this research: an exploratory fieldwork was conducted in the early stages of this research and contributed to scope out the context, landscape and stakeholders as well as to inform the methodological design of this study to ensure its applicability to data-poor contexts with agriculture as the main source of livelihoods. A subsequent extensive fieldwork was conducted at a later stage to collect qualitative data on the relationship to verify results from the quantitative analysis of census data with communities.

## 7.2 Community selection

### 7.2.1 Overall research

A combination of judgement and convenience sampling (Morse, 2000) was applied to select the case-study communities for on-site investigation among those identified as development hotspots through the data-driven study of census data described in chapter 5. Below is an overview of these criteria.

Judgement sampling allows for a selection based on existing literature, available data gathered and researcher's knowledge (Morse, 2000). Provided that this research is specifically addressing tropical cyclones, the two coastal Blocks of Rajnagar and Mahakalapada were prioritised for the final selection of villages to account for exposure to tropical cyclones, in line with results of the data-driven analysis of census data through which development hotspots were identified, which showed that most villages which experienced a high degree of change over the study period are located in these two coastal Blocks. Furthermore, village size and relevance were also used as a criterion for selection and villages with a population of more than 100 was privileged to increase the representability of quantitative findings. It was, therefore, proposed to restrict the selection to the villages listed below.

Table 7.1: Development hotspots/coldspots with a population greater than 100 (red indicates negative change, green indicates positive change; other colours are used to differentiate the villages by Block)

| BLOCK | VILLAGE | 2011 Population | 2001 Population | DELTA 2011-2001 | |
|---|---|---|---|---|---|
| Rajnagar | Chakradharpur | 964 | 818 | -9% | - |
| | Daruora | 1093 | 983 | - | 16% |
| | Dhaneswarpur | 451 | 353 | -9% | - |
| | Kusunpur | 365 | 377 | -8% | - |
| | Magarkanda | 1047 | 477 | - | 15% |
| | Tikayat Nagar | 1064 | 841 | - | 15% |
| Mahakalapada | Kharinasi | 1467 | 1198 | - | 16% |
| | Oliha | 146 | 112 | -7% | - |
| | Suniti(Bena Kandha) | 1050 | 962 | - | 17% |

Furthermore, based on the outcomes of the quantitative study on census parameters and their evolution over the period 2001-2011, it was proposed to select:

- two communities which have experienced *positive* change resulting from one predominant development attribute (i.e. number of different attributes close to minimum). Based on results of the quantitative study previously described, it was proposed that these communities are *Daruora* (where infrastructure-related variables account for two of the top five associates of change) and *Tikayat Nagar* (where communication-related and infrastructure-related variables account for two of the five major development associates each).
- two communities which have experienced *negative* change resulting from one predominant development attribute (i.e. number of different attributes close to minimum). Based on results of the quantitative study, it is proposed that these communities are *Kusunpur* and *Daneshwarpur*.
- two communities which did not experience significant change (i.e. they did not emerge as a development hotspot/coldspot). It is proposed that these communities are selected

among the 660 analysed based on their proximity to the above-mentioned four selected villages. The final selection was *Ghadiamal* and *Panchu Palli*.

In order to finalise the selection of communities, judgement sampling was combined with considerations on convenience to ensure the feasibility of the study. The following criteria were considered (cf. Abarquez & Murshed, 2004; Prasad, 2005):

- Community accessibility;
- Flood protection infrastructure in place;
- Distance within different communities.

A consultative stakeholder's workshop was organised in Bhubaneswar in the months of October/November 2016 to inform the final selection of communities building on local knowledge. The workshop was organised in collaboration with the Indian partners on the DECCMA project (Chilika Development Authority and Jadavpur University) and relevant local stakeholders were invited to attend. The organisation of a consultative workshop was particularly helpful to explore issues related to village accessibility and connectivity, as well as the presence of flood protection infrastructure (including cyclone shelters, saline embankments, etc.), building on results from the quantitative study of development changes which has shown that infrastructure may offer a very interesting cross-cutting perspective to explore disaster risk reduction issues by investigating interdependencies among different key associates. The above-mentioned villages were retained.

### 7.2.2 Communities examined during exploratory fieldwork

A preliminary scoping fieldwork was conducted in the months of August and September 2015 to ground the research questions to local reality and to inform the design of the quantitative study to be conducted thereafter. This was a key step to inform the methodological design of this thesis.

The district of Kendrapara is one of Odisha's coastal districts and it was selected due to its high exposure to tropical cyclones and to previous research having been conducted in the same region by the University of Southampton. The study was then downscaled to the municipality level, in order to identify communities that would best fit into the research.

A scoping fieldwork was conducted during the first year of this research study to preliminary explore key associates of resilience to natural hazards in the study place, in relation with existing frameworks for disaster resilience assessment and a database of resilience variables that was built from a review of over 400 scientific articles. Three coastal communities had been selected for the pilot fieldwork. Various criteria were considered while choosing target communities in the district and they primarily included (cf. Abarquez & Murshed, 2004; Prasad, 2005):

- Community accessibility;
- Exposure to tropical cyclones;
- Flood protection infrastructure in place;
- Previous research conducted by the University of Southampton in the area.

The three selected communities were Pentha, Kaitha and Kathuaganda. A general overview of relevant features of each village is provided below.

- Pentha: the village of Pentha comprises 70 households. It features a cyclone shelter that was completed in 2015 by OSDMA, a saline embankment heightened in 2013-2015 and a geo-tube wall currently under construction, both managed by the Water Resources Department of the Government of Odisha.
- Kaitha: the village of Kaitha comprises 150 households. It features a cyclone shelter completed in 1997 by the Red Cross and a saline embankment heightened in 2013-2015 and managed by the Water Resources Department of the Government of Odisha.
- Kathuaganda: the village of Kathuaganda comprises 110 households. It does not feature any cyclone shelter and it served by the shelter located in the nearby village of Nuagaon. Similarly to Pentha and Kaitha, Kathuaganda is protected by a saline embankment heightened in 2013-2015 and managed by the Water Resources Department of the Government of Odisha.

## 7.3 Methodology

### 7.3.1 Target participants

Research participants who were targeted during fieldwork include the following two categories:

1. Relevant stakeholders at the national, state and block level in India. They include representatives of disaster management authorities, local departments of agriculture, local universities, NGOs, international organisations, etc.
2. Adult residents (>18 years) of target communities who accepted to take part in the research.

#### 7.3.2 Data collection research methods

Different research methods were adopted based on research needs and target recipients as outlined in Chapter 3. They included: site surveys, semi-structured interviews to relevant institutional stakeholders and focus group discussions using Participatory Rural Appraisal techniques with participants from selected communities. Semi-structured interviews were the preferred research tool to discuss preliminary findings with relevant key informants.

A multi-phase design approach was adopted, with two rounds of fieldwork completed. A preliminary fieldwork was conducted in August-September 2015 to scope the situation. This helped in grounding the research questions to reality and in refining the methodology for the subsequent substantive analysis presented in the previous chapters. As this initial fieldwork was conducted at the onset of this PhD research, it primarily served the purpose of informing the development of the methodology chosen for this study. A second round of fieldwork was then conducted after performing the quantitative analysis presented in the previous chapters to verify quantitative evidence with the help of local communities.

##### 7.3.2.1 Preliminary fieldwork

###### 7.3.2.1.1 Semi-structure interviews

A total of 10 semi-structured interviews to 11 resource people in the previously mentioned three selected communities of Pentha, Kaitha and Kathuaganda were conducted during the five-week pilot fieldwork in August-September 2015. All semi-structured interviews to experts were conducted in English. A list of interviewed experts is annexed. Questions were targeted to recipients and modulated based on their replies. They differed among different stakeholders based on their role and position. Spontaneous contributions were also taken into account. The interviews broadly covered the following main topics:

- Strengths and weaknesses of structural protection measures (e.g. tropical cyclone shelters, embankments, etc.) in place in the case study area;
- Institutional strengths and gaps in managing disasters;
- Communication and information during emergencies;
- Socio-economic and environmental impacts of tropical cyclones on the community;
- Community dynamics in times of crisis;
- Recovery.

#### 7.3.2.1.2 FGDs

A total of 32 FGDs (16 with male participants and 16 with female participants) in the previously mentioned three selected communities of Pentha, Kaitha and Kathuaganda were conducted during the five-week pilot fieldwork in August-September 2015. Each FGD was conducted with groups of people ranging in size from 8 to 50 participants and participation of people from all represented castes, including General Caste, Other Backward Castes (OBC), Scheduled Castes (ST), and Scheduled Tribes (ST), was sought and promoted.

All FGDs were conducted in the local language, Odia, with the help of local interpreters. While the language barrier was certainly a limitation for the fieldwork, relying on interpreters who had previously worked in the field and were familiar with the topics discussed contributed to minimising translation issues. However, due to the difficulties in finding a local female interpreter, only a limited number of FGDs with female participants were facilitated by a female interpreter, while it was deemed essential to rely on a male interpreter for all remaining ones – this being another limitation of the study.

A breakdown of focus group discussions by village is provided below.

Table 7.2 - FGDs conducted during the pilot fieldwork

| | Pentha | Kaitha | Kathuaganda |
|---|---|---|---|
| **Female FGDs** | 3 | 6 | 7 |
| **Male FGDs** | 3 | 6 | 7 |

The following Participatory Rural Appraisal techniques were used during the FGDs, the advantages and limitations of which were detailed in chapter 3:

**Resource/risk mapping**. The FGD participants were asked to draw a map of their village and to locate resources (e.g., water, medical and educational facilities, financial resources, etc.). They were then invited to discuss as to whether the identified resources were sufficient and accessible to all or which categories of people hand more frequent access to one or another resource, particularly by gender. Areas that were most frequently hit by natural hazards, disaggregated by typology (e.g., cyclones, floods, droughts, etc.), were then located on the same map and elements at risk were identified. The purpose of the exercise was not to gather a physical map but to explore community perceptions around resources.

**Seasonal calendar and hazard mapping**. The FGD participants were asked to identify the dominant livelihood activities in the community and their seasonal variation, including the seasonal impacts of natural hazards. The purpose of the exercise was to assess the dependency of the community on the primary sector (agriculture) or the availability of alternative sources of livelihoods and their exposure to tropical cyclones and natural hazards.

**Historic timeline**. The FGD participants were asked to list past disaster events caused by natural hazards in chronological order and to recall any perceived progress over time in terms of risk reduction and recovery.

**Venn diagram**. A circle was drawn at the centre of a paper sheet to represent the community. The FGD participants were then invited to draw institutional services (e.g., banks, health facilities, etc.) in circles, with their distance to the community circle representing their accessibility (high distance equals low accessibility, and vice versa) and the circle's size representing significance (large circle means vital service, small circle points to low importance). This served to map institutional presence in the community with its perceived significance as well as to understand the dynamics around access to basic services.

**Daily activity clock**. On a paper sheet showing clock schedule, the FGD participants were asked to list their typical daily activities, differentiated by gender. They were then asked to describe how these listed activities were disrupted in case of a disaster and how their daily routine was altered as a consequence of those disruptions.

**Infrastructural analysis**. This exercise was specifically developed to address issues arising from any existing protective infrastructure in the community and, most notably, cyclone shelters, saline embankments, geo-tube wall and houses (concrete vs. mud houses). Participants were invited to think about each of the above-mentioned structures one by one and to discuss their strengths, weaknesses and areas for improvement. The purpose of this exercise was to explore social dynamics around the presence, functionality, use and access of protective infrastructure in place as well as any community involvement in planning.

#### 7.3.2.2 Extensive fieldwork

For the extensive fieldwork in the six target villages, two FGDs per gender group were conducted in each village during a field trip to the area in October and November 2016. In the village of Tikayat Nagar, the activities were conducted in mixed groups following a request of the village. A total of twenty-two FGDs were, thus, completed. Target participants included adult community members

(>18 years old) in the selected villages. Each FGD was conducted with groups of people ranging in size from 8 to 50 participants and participation of people from all represented castes, including General Caste, Other Backward Castes (OBC), Scheduled Castes (ST), and Scheduled Tribes (ST), was sought and promoted.

The activities were conducted in the local language, Odia, with the help of local interpreters. While the language barrier was certainly a limitation for the fieldwork, relying on interpreters who had previously worked in the field and were familiar with the topics discussed contributed to minimising translation issues.

Two types of discussions were conducted in each village:

1) A preliminary FGD to investigate which factors were perceived to be key associates of development changes by local communities through a brainstorming exercise;
2) A second FGD to understand which development changes have occurred in each community over the study period (2001-2011), how these have been perceived to impact the way communities cope with natural hazards, and how these relate with findings from the quantitative analysis.

During the first FGD, participants were asked to brainstorm by freely listing what they perceived as associates of development in their communities, independently of their relative importance. This helped in developing a common base and language for subsequent discussion. During the second FGD, participants were then asked to reflect on any development changes by listing development gains or losses (explained as improved or worsened development conditions for the community) that they had experienced during the study period. They were subsequently invited to reflect on how these improvements or deterioration of development conditions in the community had impacted the way they coped with natural hazards (and tropical cyclones in particular) during the same period and, in particular, if these were perceived as having contributed to faster recovery (explained as returning to at the least the same conditions as before the disaster) from SC 1999 and in the face of subsequent disasters. The identified development attributes were drawn on cards and participants were invited to rank those that had most or least contributed to change, both for positive and negative change, by piling up stones next to each card until consensus was reached. Finally, participants were presented with results from the statistical analysis of census data, showing the main development gains and losses recorded from the population survey, which were compared and contrasted with community perceptions.

#### 7.3.3 Qualitative data analysis

Coding is the process of sorting qualitative data (Saldana, 2015; Strauss, 1987). A data-driven inductive approach was adopted to review all qualitative data gathered from fieldwork and identify clusters and patterns (ibid.).

##### 7.3.3.1 Data preparation

The data preparation phase included a review and transcription of FGD and interview notes and recording, with information attributed to the respective source.

###### 7.3.3.1.1 Attribution versus anonymisation of data

Interviews with key informants were classified without anonymisation of the source, in line with what agreed in consent forms, to retain institutional attribution.

FGDs were numbered and an identification code was attributed to each of them, retaining information on gender and geography. The following format was adopted: FGD number gender location. For example, the first FGD conducted in Kaitha with a women-only group was classified as FGD 1F Kaitha. This identification system is used for presenting results in the following sections.

##### 7.3.3.2 Open coding, thematic clusters and patterns

The data preparation phase was followed by initial coding, whereby data were reviewed to generate open codes for the information that was found to be most relevant. This included information that was consistent and repeated across multiple FGDs, that was consistent or inconsistent with quantitative evidence, etc. (Saldana, 2015). This process facilitated the identification of thematic clusters and patterns across the data. The clusters have been used to analyse results.

### 7.4 Results from first round of fieldwork

A total of 10 semi-structured interviews to 11 resource people and 32 FGDs (16 with male participants and 16 with female participants) in the three selected communities of Pentha, Kaitha and Kathuaganda in the Rajnagar Block of the Kendrapara District of Odisha were conducted during a five-week scoping fieldwork in August/September 2015. Major findings that emerged from this preliminary fieldwork and that are most useful for this study can be ascribed to the following key thematic clusters and are described in more details in the sub-sections below:

- Location and use of cyclone shelters;
- Local perceptions on saline embankments and other coastal infrastructure;
- Safety nets;
- Impact of cyclones on agricultural livelihoods and related adaptation strategies;
- Communication and dissemination of disaster-related information;
- Education and training on disaster risk reduction.

Overall community participation in the activities was found to be high in Kaitha and Kathuaganda, where locals gave their availability to participate in more FGDs; residents of Pentha, on the other side, were less willing to participate in the research, most probably due to the increasing number of NGOs, universities and other organisations investigating in the area.

The results from this preliminary fieldwork informed the refining of the methodological design of this research study, from the verification of data availability to the development of a data-driven, mixed method approach suitable for data-poor contexts, while taking into account the dominant role of agriculture as a source of livelihoods and its perceived strong association with recovery from tropical cyclones.

### 7.4.1 Location and Use of Cyclone Shelters

All existing cyclone shelters in the state of Odisha have been constructed and managed by either OSDMA or the Indian Red Cross. While only 23 cyclone shelters were constructed prior to SC 1999 (all by the Indian Red Cross), after 1999 the Government of Odisha commissioned the Indian Institute of Technology (IIT) Kharagpur to conduct a scientific survey to identify the most suitable locations for additional cyclone and flood shelters to be funded in phases through different funding options that were made available through the years, including the World Bank assisted National Cyclone Risk Mitigation Project and Integrated Coastal Zone Management Project (OSDMA, 2012). Multipurpose cyclone shelters were constructed on the coast while flood shelters were built in other parts of the state that are not of interest for this research and will therefore not be further mentioned. In 2012, OSDMA had constructed 135 multipurpose cyclone shelters and 165 more were in the pipeline for edification (OSDMA, 2012).

An interview with OSDMA contributed to gaining a deeper understanding on the scientific criteria that were used for the identification of the ideal locations of these shelters. The concept of a ‘service community’ was introduced to define municipalities that host shelters within their boundaries (Mishra, 2015). This approach, therefore, favoured the construction of shelters within villages and not in neutral territories at the intersection of several villages, based on the idea that a shelter is more properly maintained and less exposed to damages and negligence if located in a populated area. Two main criteria were adopted (OSDMA):

- ‘No person will have to travel more than 2.25 km to get a safe shelter and without crossing a natural Barrier.
- The building is designed to withstand wind speed up to 300 kmph and moderate earthquakes. Its plinth is above High Flood line (HFL) and standing on a stilted floor, it can remain unaffected in storm surge up to the 1st floor level’.

The issue of the location and accessibility of cyclone shelters is of great interest for this research and it was one of the most significant issues emerged from FGDs in the three selected communities. Among the target villages, Pentha is home to a multipurpose cyclone shelter completed by OSDMA in 2015; Kaitha hosts a multipurpose cyclone shelter constructed by the Indian Red Cross in 1997; and Kathuaganda features no cyclone shelter within its boundaries but it is served by the nearby village of Nuagaon (1-km distance) in this regard.

The cyclone shelter in Kaitha was, thus, built before 1999 and, based on findings from FGDs, it was used three times in emergency: in 1999 (SC 1999), 2013 (cyclone Phailin) and 2014 (cyclone HudHud). It consists of two rooms and one latrine is present. During peace time, it is used for school purposes (the existing school in the village is used for grades 1 to 5, while the shelter is used for grades 6 and 7) and as a community hall for community meetings, festivals and wedding celebrations. An overview of local perceptions of the shelter as emerged from the FGD on infrastructural analysis and validated by discussions around the different PRA tools used is provided in the table below, based on triangulation of information supplied by women and men respectively. A Cyclone Management Committee (CMC) was formed by the Indian Red Cross at the time of the edification of the shelter, but no training has been provided ever since.

Table 7.3: Highlights on local perspectives on cyclone shelter in Kaitha from FGD, showing strengths, weaknesses and suggested improvements

| Positive | Negative |
|---|---|
| • Life saver (FGD 1F, 1M, 2F, 2M, 3F, 3M, 4F, 4M, 5F, 5M, 6F, 6M Kaitha) | • One latrine is not sufficient (FGD 6F, 6M Kaitha) |
| • Multipurpose (used as a community hall and for school purposes) (FGD 1F, 1M Kaitha) | • No electricity available (FGD 6F, 6M Kaitha) |
| • Can be used to store food in emergency (FGD 2F, 2M Kaitha) | • No water available in emergency (a hand well is located in proximity of the shelter; |

| | |
|---|---|
| | however, the hand pump is broken during cyclones and water becomes unavailable) (FGD 6F, 6M Kaitha) |
| • Presence of a siren for alerting local population (FGD 3M Kaitha) | • Lack of space (FGD 1F, 1M, 6F, 6M Kaitha) |
| | • No facilities for pregnant women (e.g. equipment, hot water) (FGD 6F, 6M Kaitha) |
| **Suggested Improvements** | |
| • Separate toilet facilities for ladies and gentlemen (FGD 6F, 6M Kaitha) | |
| • Dedicated toilet facilities for special needs (disabled, pregnant women, etc.) (FGD 6F, 6M Kaitha) | |
| • Generator and water tank (FGD 6F, 6M Kaitha) | |
| • More equipment (currently only one rope and few life jackets available) (FGD 6F, 6M Kaitha) | |
| • Training of the task force (FGD 1F, 1M, 6F, 6M Kaitha) | |
| • Ramp(FGD 6F, 6M Kaitha) | |
| • Need for a shelter caretaker (FGD 1F, 1M, 6F, 6M Kaitha) | |
| • More space (so that separate female/male rooms can be created) (FGD 6F, 6M Kaitha) | |

Pentha features a recently completed multipurpose cyclone shelter constructed by OSDMA. It was still under construction during cyclone HudHud in 2014, which is the only time it was used so far for emergency purposes. Pentha is the only beneficiary of the shelter and people from no other villages are served by it; the local school located just in front of the shelter has also been used at the time of HudHud for additional space. Prior to the edification of this shelter, villagers used to commute to the closest cyclone shelter available in a neighbouring village (5-km distance). The only criticism to the structure is the lack of supplied equipment; perceptions on the shelter are otherwise positive. A village Disaster Management Committee has been formed by OSDMA, but no training has been provided yet.

Finally, Kathuaganda is the only community among the selected ones that does not host any shelter but is served the nearby multipurpose cyclone shelter in Nuagaon (1-km distance, with poor road connection), which was used only one time by Kathuagandans in 2013 (cyclone Phailin). Several issues emerged during discussions with residents around access to the shelter, with locals reporting tensions and conflict with residents of Nuagaon to the extent that they allegedly preferred to remain in Kathuaganda or to rely on family bounds to be temporarily hosted by family members living in safer villages when cyclone HudHud hit the area one year later, rather than commuting to Nuagaon again. No Disaster Management Committees are in place in the village. An overview of local perceptions of the shelter in Nuagaon is provided in the table below.

Table 7.4 Highlights on local perspectives on cyclone shelter in Kathuaganda, showing strengths, weaknesses and areas for improvement

| Positive | Negative |
|---|---|
| • Existence (FGD 1-7 F, 1-7 M Kathuganda) | • Distance (a 30-min walk in normal conditions; it took 1h to 1h30 during Phailin) (FGD 1F, 1M, 2F, 2M, 6F, 6M Kathuaganda) |
| • Presence of toilet facilities (FGD 1F, 1M Kathuaganda) | • Lack of cooperation from residents of Nuagaon (FGD 1F, 1M, 2F, 2M, 6F, 6M Kathuaganda) |
| • Generator (FGD 1F, 1M Kathuaganda) | • Lack of space (FGD 1F, 1M Kathuaganda) |
| | • Toilet facilities not sufficient (FGD 7F, 7M Kathuaganda) |
| | • No facilities for pregnant women (FGD 7F, 7M Kathuaganda) |
| | • No water (FGD 1F, 1M Kathuaganda) |
| **Suggested Improvements** | |
| • Cyclone shelter in Kathuaganda, with toilet facilities, a generator, a water tank and rescue materials, including a siren (FGD 7F, 7M Kathuaganda) | |
| • For the shelter in Nuagaon, separate toilet facilities for women and men, rescue equipment (including medicines and a first aid kit), water, electricity, facilities for disabled (FGD 6F, 6M, 7F, 7M Kathuaganda) | |

### 7.4.2 Local Perceptions on Saline Embankments and Other Coastal Infrastructure

A coastal saline embankment that was heightened in 2013-2015 protects all three communities. A geo-tube wall was under construction in Pentha at the time of this research. An overview of local perceptions on the embankment collating information collected in all three villages is provided in the table below. While the geo-tube wall has not been yet completed, great skepticism around its quality was reported from FGDs in the three communities.

Table 7.5: Highlights on local perspectives on the saline embankment in all three communities, showing strengths, weaknesses and areas for improvement

| Positive | Negative |
|---|---|
| • Decrease of salinity in agricultural fields (FGD 2M Pentha; 2M, 6M Kaitha; 2M, 6M Kathuaganda) | • Limited effect against wild animals (FGD 2M Pentha; 2M, 6M Kaitha; 2M, 6M Kathuaganda) |
| • Decrease of agricultural losses/Increased soil fertility (FGD 2M Pentha; 2M, 6M Kaitha; 2M, 6M Kathuaganda) | • Water entering from culverts (no gate) where in place (Kathuaganda); water logging when no culverts are present |

| | |
|---|---|
| | (Kaitha) (FGD 2M Pentha; 2M, 6M Kaitha; 2M, 6M Kathuaganda) |
| • Improved mobility/connectivity (road on the embankment) (FGD 2F, 2M Pentha; 2F, 2M, 6M Kaitha; 2F, 2M, 6M Kathuaganda) | • Breaches (FGD 2M Pentha; 2M, 6M Kaitha; 2M, 6M Kathuaganda) |
| • Saves life and livestock (FGD 2F, 2M Pentha; 2M, 6M Kaitha; 2M, 6M Kathuaganda) | |
| • Barrier against wild animals (FGD 2F Pentha; 2F, 2M Kaitha; 2F, 2M Kathuaganda) | |
| • Increased productivity of vegetable gardens (FGD 2F Pentha, Kaitha and Kathuaganda) | |
| • Provided job opportunities (FGD 2M Pentha) | |
| **Suggested Improvements** | |
| • Iron net against wild animals (FGD 2M Pentha) | |
| • Stone filling of culverts; culverts (FGD 2M Pentha) | |
| • Afforestation between the embankment and the sea to fight coastal erosion and protect the embankment/road (FGD 2M Pentha, 2M Kaitha, 2M Kathuaganda) | |
| • Paved road on the embankment (FGD 2F, 2M Pentha, Kaitha and Kathuaganda) | |

### 7.4.3 Safety Nets

The strength and weaknesses of the main governmental programmes for poverty reduction were investigated in the selected villages. While the use of BPL cards, giving access to a number of state-subsidised products and services to people living in conditions below the poverty line, is quite widespread in all communities, major issues in the shortlisting of people who can benefit from the scheme emerged from the analysis. In all three communities, it was reported that the lists of beneficiaries have not been updated for a long time and the scheme does not therefore necessarily target people mostly in need. Key informants in local NGOs confirmed that these lists have been last updated in 1997. BPL cards give access to a number of other welfare schemes, such as the Public Distribution Service (PDS) and the Pradhan Mantri Gramin Awaas Yojana (PMAY). Shortcomings of the PDS, detailed in Section 2.4.4 of this report, were found to be related to the accessibility of the scheme and therefore linked to BPL cards. As regards PMAY, this housing scheme has been designed to grant subsidies to the low-income population for building affordable housing. BPL card owners in all coastal communities of Odisha can benefit from the scheme, which has been particularly designed to provide incentives for the construction of concrete houses in replacement of less resistant mud houses. Outcomes of FGDs with community members in the target communities, however, have highlighted the shortcomings of this programme: while several concrete houses were built under this scheme in Kaitha and Kathuaganda, in the majority of instances local villagers have reported using them for stocking items while maintaining mud houses as their primary residence due to the greater availability of space. It has been pointed that subsidies provided by the Government are sufficient to build a one-bedroom concrete house, which lacks space compared to traditionally larger mud houses. Finally, the strengths and weaknesses of the NREGA programme (see Section 2.4.4 for more details) were explored with community members: while being aware of the programme, local villagers in all three communities reported not to have been involved on it and acknowledged that the major infrastructural development works in the area, e.g. the construction of the saline embankments, required a skilled workforce and labour from other States was consequently employed.

### 7.4.4 Impact of Cyclones on Agricultural Livelihoods and Related Adaptation Strategies

Agriculture was confirmed to be the dominant source of livelihoods for the sampled population, heavily exposed to the impact of natural hazards, making it by far the greatest preoccupation in the face of cyclones and perceived as intrinsically connected to recovery and a direct measure of it.

An interview with a key resource person at Odisha University of Agriculture and Technology (OUAT) contributed to gaining an understanding of the latest technologies and achievements in the field of climate-resilient agricultural seeds in the context of Odisha. While extensive experimental projects for creating seed banks have been put in place, focus group discussions in the selected communities in Rajnagar Block informed that the local population is mostly unaware of the existence of such varieties which are not used or accessible in the study site.

### 7.4.5 Communication and Dissemination of Disaster-Related Information

In all three communities, the population did not report communication and information as a major issue in disaster management. Media communication of disaster information was deemed sufficient and television was reported as the main source of information on weather and cyclone forecasts. A significant improvement in information communication thanks to the availability of new technologies in the case of the 2013 and 2014 cyclones compared to the past (cf. 1999) emerged from activities in all communities. Awareness-raising campaigns and other initiatives organised by local NGOs and other organisations were reported as the major reason for the reduced impact of cyclones over time.

### 7.4.6 Education and Training on Disaster Risk Reduction

Training related to disaster risk reduction has been reportedly provided by the Indian Red Cross in Kaitha at the time of the construction of the cyclone shelter in 1997 when a disaster management committee was also formed in the village; however, no additional training nor further meetings were organised. Community members expressed the need to receive training on how to use the equipment stocked inside the shelter. No disaster management committee is in place in Kathuaganda, where community members have recently been contacted by OSDMA and provided with SIM cards for communication. No formal training process is in place as of yet though. Similarly, OSDMA has been facilitating the establishment of a disaster management committee in Pentha; however, disaster risk reduction-related trainings are yet to be organised. These preliminary findings suggest that communities hosting a cyclone shelter may be better positioned in receiving training and information from local authorities, although this would require further investigation.

## 7.5 Results from second round of fieldwork

When asked to brainstorm on which associates of development they considered fundamental to enhance their wellbeing and ultimately the way they cope with natural hazards, respondents in the six selected villages compiled a list of factors, many of which pertain to the categories already identified in the quantitative analysis above. The full list of development factors that are key to the target communities' wellbeing is provided in Table 7.6, by village and gender group. In Table 7.7, these factors are aggregated and classified in the categories identified in the data-driven analysis of past changes. A major finding is that, as expected, several of the associates of development identified by locals pertain to the institutional sphere, which was not accounted for in the quantitative analysis. It is particularly interesting to consider the first five associates that were identified by each group to identify which of the above-mentioned categories (Communication, Infrastructure, etc.) remain dominant and whether this coincides with or differs from key results of the quantitative analysis.

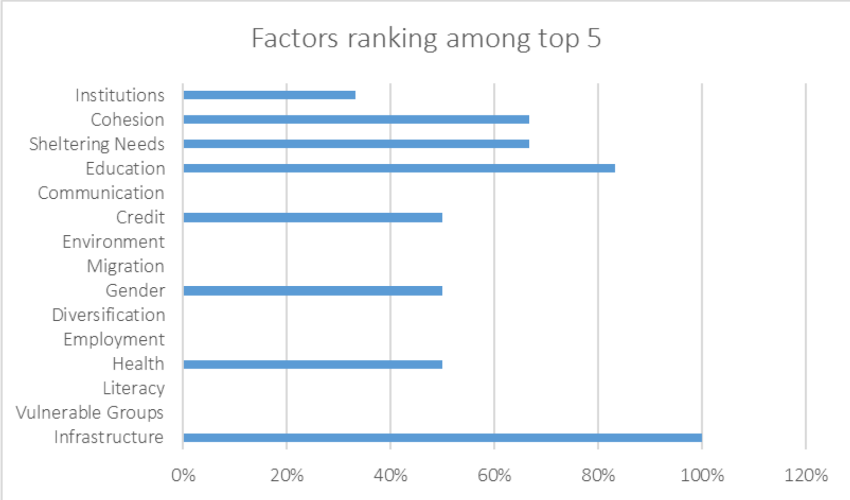
Table 7.6: Key associates of development by village and gender group

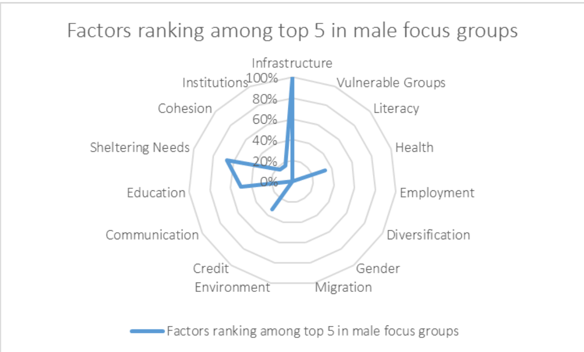
| Brainstorming on development drivers (in order of mention) | |
|---|---|
| **Daruora, men's group** | **Daruora, women's group** |
| Shelter | Health services |
| Bank | Ration card |
| School | School/college |
| Health centre (with doctor) | Playground |
| Drinking water (T-wells) | Water |
| Agricultural services | Shelter house |
| Agricultural works (canal for irrigation) | Job card |
| Road | Bank branch |
| Latrins | Irrigation |
| Safety nets (ration card, Indira Was, death support sc | Medicines (cold, fever, first-aid box) |
| Drainage | Road |
| Employment | Maternal/child care (ASHA) |
| Playground | TV |
| Club house | Teachers |
| Hospital | Books (Govt provides book up to 8th grade, not for 9th-10th grades) |
| Environmental protection (vs. prawn culture polluting agricultural fields) | |
| **Tikayat Nagar (mixed group as per village request)** | |
| School | |
| Concrete roads | |
| Hand pumps | |
| Drainage | |
| Cyclone shelter in the village | |
| Livelihood development (cf. industrial plants) | |
| Health/medicines | |
| Maternal/child care (ASHA) | |
| Education | |
| Bus | |
| Protection against wild animals (from mangrove forests) | |
| Self-Help Groups | |
| **Ghadiamal Men** | **Ghadiamal Women** |
| Shelter house | T-well |
| Roads within the village | Road |
| Medical facilities | School |
| School | Health/medicines |
| School playground | Toilets |
| Agricultural support | Shelther house (facilities for pregnant women) |
| Irrigation | Drainage |
| Toilets | Free of charge gas for cooking |
| TV | Ration card |
| Employment | Relief food |
| Disability | Pension |
| Mobile phones/Internet (1 young interviewee) | Female jobs (e.g., tailoring - machines & training) |
| | Agricultural services (subsidised fertilisers & seeds, crop insurance - corruption) |
| | Nursery |
| | Health card (50% of the population has one) |
| | Bank branch |
| | Indira Was (corrupt system) |
| **Panchu Palli Men** | **Panchu Palli Women** |
| Cyclone shelter | Upper primary school (5th-7th grade) |
| Bank | Veterinary services |
| Concrete road (in the village) | Medical facilities (specialists in child/maternal care) |
| Toilets | Cyclone shelter |
| T-wells | T-wells |
| Club house | Toilets |
| Concrete houses | Drainage |
| Irrigation | |
| Community pond | |
| Drainage | |
| **Kusunpur Men** | **Kusunpur Women** |
| Roads within the village | Self-Help Groups |
| T-wells | Toilets |
| Indira Was | Club house for Self-Help Groups meetings |
| Toilets | |
| **Dhaneswarpur Men** | **Dhaneswarpur Women** |
| Road | Space for Self-Help Groups meetings |
| Concrete houses | Roads |
| Water | Hand pumps |
| Toilets | Self-Help Groups livelihood development trainings (fish cultivation in the pond) |
| Electricity | |
| Stone packing (land loss due to soil erosion) | |
| Drainage | |
| Roads within the village and to the river (cf. river burials) | |
| Canal for drainage | |
| Water pond | |
| Land | |
| Shelter house | |

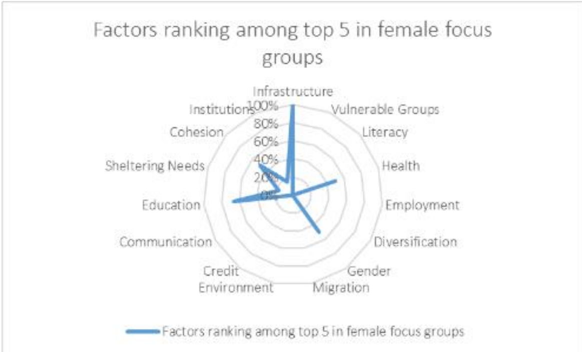
Table 7.7: List of key associates of development as identified by local communities

| Development drivers | | |
|---|---|---|
| Communication | | TV |
| Communication | | Mobile phones |
| Communication | | Internet |
| Infrastructure | | Shelter house |
| Infrastructure | | T-wells |
| Infrastructure | | Community pond |
| Infrastructure | | Irrigation |
| Infrastructure | | Roads |
| Infrastructure | | Toilets |
| Infrastructure | | Electricity |
| Infrastructure | | Bus |
| Infrastructure | | Drainage |
| Infrastructure | | Gas |
| Employment | | Employment |
| Employmen | Gender | Female employment |
| Employment | | Land |
| Credit | | Bank |
| Credit | Gender | SHG |
| Education | | Education facilities |
| Education | | Nursery |
| Education | | Teachers |
| Education | | Books |
| Education | | Livelihood development |
| Health | | Health facilities |
| Health | | Medicines |
| Health | | Maternal/child care |
| Health | | Veterinary services |
| Vulnerable Groups | | Disability |
| Cohesion | | Playground |
| Cohesion | | Club house |
| Environment | | Environmental protection |
| Institutions | | Ration card |
| Institutions | | Health card |
| Institutions | | Indira Was |
| Institutions | | Death support scheme |
| Institutions | | Agricultural services |
| Institutions | | Pension |
| Institutions | | Job card |
| Institutions | | Relief food |

Table 7.8: Percentage of times each category was cited as at least one of the top five associates of development by either men or women (top), by men (bottom left), by women (bottom right)




When considering the top five associates of development identified by each group and calculating how many times at least one of the first five associates belongs to each category (Communication, Infrastructure, etc.), it emerges that elements pertaining to the infrastructural sphere are cited as at least one of the five top associates by either men or women in 100% of the instances, followed by elements pertaining to the educational sphere (83%), Sheltering Needs and Cohesion (both at 67%), Health, Credit and Gender (50%), and finally Institutions (33%), whereas all other categories do not feature among the first five factors important for development (Table 7.8, top). While several of the associates of development mentioned by the local communities refer to institutions, these do not feature among the ones they prioritised. If we then look at which associates were identified as the top five by women during female focus group discussions (Table 7.8, bottom right), Infrastructure continues to rank first with 100% of incidences, while Education is at 67%, followed by Cohesion, Health and Gender at 50%, and Sheltering Needs and Institutions at 17%. When analysing men's priorities (Table 7.8, bottom left), Infrastructure stays at 100%, Sheltering Needs is at 67%, Education at 50%, Credit and Health at 33%, and Cohesion and Institutions at 17%. These findings already confirm that infrastructure is perceived as a key issue for development and are in line with results of the quantitative analysis of census data which show that most of the development changes that occurred over the study period and contributed to improving life conditions in the communities which have experienced them pertain to infrastructure and that infrastructure seems to be a cross-cutting issue in past development gains and losses. A further investigation of which development changes have taken place over the period 2001-2011 in the target communities according to locals has been pursed to understand whether the gains and losses identified through the quantitative analysis have been experienced by local people and which other changes may not have been captured by the data-driven analysis.

The five main associates of past development gains or losses in the four selected development hotspots (two positive and two negative) that emerged from the quantitative analysis of census data are reported in Table 7.9. The top five associates of positive change have been considered for positive development hotspots (Daruora and Tikayat Nagar), while the top five associates of negative change have been considered for negative development hotspots (Kusunpur and Dhaneswarpur). The remaining two villages (Ghadiamal and Panchu Palli) have experienced an average zero-change over the study period.

Table 7.9 Top five associates of change in the selected development hotspots from quantitative findings

| **Community** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Daruora | Community services (recreational and cultural facilities) | Newspapers | Bus | Water | Diversification |
| Tikayat Nagar | Community services (recreational and cultural facilities) | Newspapers | Road | Water | Maternal/childcare |
| Kusunpur | Phone | Main workers | Bus | Female lit. | Additional shelters |
| Dhaneswarpur | Maternal/childcare | Main workers | Bank | Male adults | Additional shelters |

Communities were asked to map development changes that took place in their communities over the period 2001-2011. Results of this mapping exercise are provided below.

*Positive development hotspots: the case of Daruora and Tikayat Nagar*

It was found that, in the communities that have experienced positive change, improved road connectivity, including the construction of a concrete access road to the village, was a major factor of change, driving the enhancement of collateral services, such as bus services and access to newspapers, as also reflected in the quantitative findings. Improvements in water availability highlighted in the data-driven analysis did not significantly impact local residents and either went rather unnoticed (in Daruora) or continue to be perceived as insufficient (in Tikayat Nagar). The availability of maternal and childcare services at a reduced geographical distance (within the village, since the last four or five years) was also experienced as one of the key associates of change in Tikayat Nagar; however, the effective availability and quality of the service remain questionable. In Daruora, the role played by diversification was confirmed by local residents and attributed to increased seasonal migration among young people, as well as, partly, to the development of prawn culture activities in the area, which is, however, perceived to impact negatively the community due for polluting agricultural fields. Finally, no changes were experienced in terms of the availability of community services in the community, with no new recreational or cultural facilities built in between 2001 and 2011, contrary to what emerged from the census data analysis. Overall, positive examples of community-based development initiatives for disaster risk reduction reported by local residents include the collection of village funds for the construction of a ground-floor livestock shed by closing the bottom level of the elevated school cum shelter in the village, as well as the rental of a generator before in preparation for cyclones Phailin and HudHud. The Village Development Committee was held responsible for these initiatives and for their implementation, and was reportedly very active in the community, with citizens feeling that their community worked more effectively than larger, neighbouring communities such as Ghadiamal thanks to a stronger social cohesion. The major development changes reported by villagers of Tikayat Nagar relate primarily to construction of a concrete road leading to the primary school in the village and the nearby municipality of Talchua, where health, bank, shelter and educational facilities (other than nursery and primary school) are located; however, significant challenges in reaching other localities farther than Talchua (including Rajnagar for hospital services) persist due to poor road connectivity, which also represented a major challenge for reaching the community during fieldwork. Furthermore, the construction of a local primary school in the village is very recent (it was inaugurated in 2009 and completed in 2012) and changes in literacy levels as well as employment opportunities have only been partially captured from 2011 census data. In terms of employment, the primary source of livelihoods is the village is fishing, as opposed to all other five communities where agriculture is dominant. While both activities are seasonal and performed over the same number of months per year (a fishing ban is in function due the turtle reproduction period from November to April), fishing is reportedly perceived by locals as more resilient to tropical cyclones as recovery can be faster. Finally, female employment was cited as one of the major development changes by interviewed residents, with 90-95% of the female population being formally or informally employed in labour and fishing activities. While environmental protection offered by mangrove forests did not change over time, it was perceived as a key factor for reducing exposure to disaster risks. All in all, infrastructural development (cf. roads and collateral services), social cohesion, increased literacy and female employment emerged as the main perceived positive factors for change, resulting in a better ability to cope with natural hazards.

*Zero change communities: the case of Ghadiamal and Panchu Palli*

Ghadiamal and Panchu Palli are two of the communities that did not experience significant change over the ten-year study period and have, therefore, not emerged as development hotspots. Fieldwork was conducted in these communities to understand why they were not affected by change as opposed to some of their neighbouring villages. It emerged that the lack of a sense of community and social cohesion was the main challenge faced by residents of Ghadiamal. While the village itself is larger in size and potentially better placed than nearby communities such as Daruora in terms of facilities (for instance, it features a cyclone shelter built in 2003 by Care India, as well as educational facilities up to high school level), the absence of a Village Development Committee and the spatial division of the community into four wards have been reported as key obstacles and limitations for community development. Poor road connectivity within wards is also seen as contributing to spatial and social isolation. There is a general feeling in the population that disaster risk reduction and development initiatives are a responsibility of the government and no community-based initiatives have reportedly been undertaken. Similarly, in Panchu Palli, political tensions and the lack of social cohesion have been reported as major causes of inertia. When single development initiatives, such as the construction of a cyclone shelter in Ghadiamal (also serving Panchu Palli), have been undertaken, the lack of ownership and the scepticism around the solidness of these initiatives caused by unfinished works and lack of maintenance (e.g., the toilets in the shelter have not been completed) have led to a general mistrust in the effectiveness of these solutions. The location of the shelter house in a neutral territory just outside the village, in front of the local high school, has led to a lack of maintenance and sense of appropriation; as a consequence, there have been episodes of looting and the shelter is not perceived as a safe place by the great majority of the population.

*Negative development hotspots: the case of Kusunpur and Dhaneswarpur*

Among the selected communities, Dhaneswarpur is the one located at a shortest distance (<2km) from the Block capital of Rajnagar, where medical and higher education facilities are located. This has been demonstrated to play a role in better access to education. The village features a clear spatial distribution divide, with the main and secondary concrete roads in the village hosting mostly concrete houses and the remaining area of the village characterised by mud roads and mud houses. This divide has emerged during focus group discussions and has been interestingly attributed to differential degrees of education. Separate focus group discussions were held in the two parts of the village to further investigate the issue and ensure that the viewpoints of all parts was captured. It has emerged that the differential education levels among the population are perceived to be reflected into spatial distribution and quality of housing across the village. In particular, it was found that the concrete houses in the village mostly belonged to people with a higher degree of education, independent of caste, and were predominantly located along the two concrete roads crossing the village (with a spatial separation by caste), while people with a lower degree of education predominantly inhabited mud houses with poor connectivity to the rest of the village. This separation was reportedly reflected in everyday life in the community, without proper representation of both groups in decision making. In Kusunpur, the absence of elections for village leaders and village development committees and the practice of inheriting these roles were reported as major causes of tensions, disunity and malfunctioning.

## 7.6 Discussion

Findings from the initial fieldwork contributed to grounding the research questions to local reality, verifying available data with key informants then complemented by a systematic review of literature, and shaping the methodological design of the research, building on the strong perceived association of agricultural productivity with post-disaster recovery and the data-poor context. This founded the basis for developing a data-driven approach to look at past socio-economic, environmental and infrastructural gains and losses complemented by an estimation of post-disaster recovery rates using crop yield as a proxy measure from satellite earth observation.

The final round of fieldwork then verified quantitative evidence. Overall, infrastructure has unanimously emerged as the associate of development most significantly impacting communities, with consistent results across the quantitative and qualitative parts of this research study. The improvements driven by infrastructural changes, for example in terms of collateral services (transportation; access to medical, educational and other facilities; etc.), are perceived to have had the greatest impact on communities, as also demonstrated by strategic evidence of change. Several studies have investigated the key role played by critical infrastructure (e.g., transport, water and wastewater facilities, public health, emergency services) in successful disaster management, most notably for ensuring communication and the delivery of supplies before, during and after an emergency (cf. Manoj and Hubenko Baker, 2007). Mendonça and Wallace (2006) have found that interdependencies among critical infrastructural systems are a core issue in dealing with infrastructure-related disruptions during emergencies due to the cascade effects they are responsible for, and findings from this quantitative analysis seem to reaffirm this observation. Infrastructural developments also play a role in reducing distances and, as a consequence, in improving the speed at which the population can access basic services and facilities, and at which humanitarian operations can take place (Goldschimdt & Kumar, 2016). Transportation decisions, in particular, have been found to be fundamental for disaster risk management (Goldschimdt & Kumar, 2016).

Furthermore, the uneven impact of disasters on different social groups, as well as the need to integrate social vulnerability discourses in disaster and development studies based on the assumption that disaster risk and impacts are distributed in ways that reflect social constructs, has been largely discussed in literature and the disparities deriving from age, gender, class and other shades of social differences behind this differential burden have been widely assessed in practice (cf. Few et al., 2016; Finch, Emrich, & Cutter, 2010; Adger, 2006; Kahn, 2005; Fordham, 2003; Cutter, Boruff, & Shirley, 2003; Hewitt, 1997; Phifer, 1990). This has emerged from findings of the quantitative analysis, which demonstrated that issues related to vulnerable groups had a significant impact on change. The differential impact of disasters by gender, age and disability has been confirmed during focus group discussions; caste, however, has been consistently denied to play a role in disaster risk reduction efforts in focus group discussions in all communities and this issue requires further investigation with the help of other research instruments, allowing for a more in-depth analysis, to better understand the dynamics behind this.

In terms of communication, the key role played by media in disseminating timely information about upcoming natural hazards has been acknowledged as a significant, recent gain in all communities and a positive consequence of the electrification of their villages. Television was confirmed to be the primary source of information nowadays, followed by mobile phone, and no significant differences emerged across communities in relation to communication aspects. The availability of a television in each household was not reported as a necessary condition for having access to disaster-related information, with word of mouth and shared access to information being predominant features in the communities. Access to official information on impending hazards was reported only in Ghadiamal and Panchu Palli, while in Tikayat Nagar one individual was reportedly part of the cyclone shelter management committee of the nearby village of Talchua. Major issues in disseminating this information have emerged, with the large majority of the interviewed population being unaware of these initiatives.

When looking at qualitative evidence of perceived past development gains and losses in the selected development hotspots, it emerged that social cohesion and ownership of development initiatives are key to success. The literature confirms the need to help communities develop and implement small disaster risk reduction efforts to overcome political constraints and build a sense of appropriation that can help drive continuous efforts over time, with ownership and partnership being key principles of community-based disaster risk management (Few et al., 2016). The case of Daruora, where several disaster risk management activities were undertaken by residents using village funds, prove the positive contribution of self-initiative and social cohesion for successful disaster risk reduction. This also demonstrates the role played by fair and equal community leadership, ensuring partnership and the participation of different actors, in driving collective efforts and initiatives. The case of Daruora, as opposed to that of Ghadiamal, Panchu Palli, Kusunpur and Dhaneswarpur, consolidates this finding.

Finally, the role of institutions has been investigated by numerous studies (cf. Raschky, 2008). While it was not captured by the quantitative part of this research study, the topic was raised in all focus group discussions, especially with reference to safety nets (cf. government schemes for concrete houses, toilets and support after a family death). However, significant issues around accessibility to these schemes and corruption were mentioned. This did not seem to impact communities in a differential manner.

In conclusion, findings from this study demonstrate that developments relating to infrastructure, communication, inclusion, ownership and partnership, and social cohesion are perceived to play the most significant role in enhancing a community's ability to cope with natural hazards in the six selected communities. Issues around these associates of development help understand the differential development of communities in the study area and how communities perceive to be best or worst placed in the face of natural hazards compared to their neighbouring communities, in an attempt to map tangible gains and losses which are perceived to increase or decrease community capacities for disaster risk reduction.

## 7.7 Conclusions

In conclusion, fieldwork with local communities at the early stages of this research proved a fundamental step to ensure that the research design would be suited to the local context and to community perceptions of the relation between disasters and development.

A data-driven approach was then used to investigate past development gains and losses in the study site and to identify key development hotspots which have experienced significant change, whether positive or negative, over a ten-year period between 2001 and 2011. Results from this study show that the major attributes of development in the study site pertain to the domain of communication, infrastructure, gender and vulnerable groups, and present useful insights on the mutual interactions between the different development factors.

To overcome the data availability limitations affecting the quantitative part of the study, the statistical analysis was complemented by an on-site qualitative verification of community perceptions, following recommendations to use mixed methods for development research (cf. Weichselgartner & Kelman, 2015; Barrett & Constas, 2014; Cardona, 2003) and to minimise the expert-community divide (cf. Weichselgartner & Kelman, 2015).

Verification on the ground of perceived key associates of development to understand whether community perceptions of change coincide with or differ from strategic evidence of change confirmed the key role played by infrastructure and shed light on the importance of ownership, partnership and social cohesion for driving positive change in the face of natural hazards.

This contributes to providing an evidence-based understanding of development changes in the region and their spatial-temporal characterisation, with the aim of identifying minor but tangible evidence of the differential impact of development on a community’s ability to recover from disasters.

While community perceptions confirmed quantitative evidence, they also contributed to the identification of areas and parameters that were not accounted for in the data-driven analysis and which would need to be further researched to complement results. This is particularly true for institutional drivers (cf. policy, availability and accessibility of local institutions) and the role of seasonal migration, which were not properly captured in the quantitative analysis, despite having proven to act as constraints and incentives for disaster propensity (Neumayer, Plumper, & Barthel, 2014), development resilience (Bassett and Constas, 2014) and disaster impacts (Mochizuki et al., 2014).

Further research is needed, on one side, to demonstrate the linkages between all mapped associates of development and perceived community resilience to natural hazards in the region, to identify connotations of resilience in the area and build case studies of resilience, and, on the other side, to scale up community based evidence of perceptions of development and the mutual implications for resilience at the district level.

# Chapter 8: Discussion and conclusions

## 8.1 Key findings

This research attempted an ambitious investigation of how differential post-disaster recovery relates to the many socio-economic, environmental and infrastructural dimensions of development to fill what was identified as a knowledge gap in literature. It did so by drawing evidence from SC 1999, one of the worst tropical cyclones in global history, as a case study, in an area of India where significant improvements in disaster risk management have since contributed to saving lives in the face of more recent extreme events, but the loss of predominantly agricultural livelihoods because of tropical cyclones remains a key development issue.

A novel methodology was developed to screen socio-economic, environmental and infrastructural development gains and losses in a data-poor context, and their correlation with post-disaster recovery rates, with verification of community perceptions. Mixed methods were used to address the complex nature of the issue, starting at a larger scale (District level) and gradually zooming in down to the village level. A data-driven approach so as to overcome some of the limitations of eminence-based frameworks in favour of evidence-based models.

This thesis offers contributions in three main areas:

i. A *theoretical* contribution, evidencing that speed of recovery is primarily associated with infrastructure, communication and social cohesion;
ii. A *methodological* contribution, whereby the data-driven approach designed for this research appears to capture the situation quite well, with quantitative evidence of change matching qualitative evidence of community perceptions;
iii. An *empirical* contribution, which also signifies the *limitations of the methods* used, showing that the methodology is suitable for contexts where the primary sector represents the main source of livelihoods, given that it primarily captures agriculture-related recovery, but not necessarily for other areas. Similarly, it mainly captures physical losses, while other types of losses (e.g., health-related) at the local level remain underreported, making it challenging to assess recovery at the micro-scale.

These contributions are further detailed in the sections that follow.

### 8.1.1 Main findings by research objective

The aim of this research study was to characterise the relationship between pre-disaster socio-economic, infrastructural and environmental development with the rate and type of post-disaster recovery at the community level. This translated into the following research objectives:

I. Identify socio-economic, environmental and infrastructural losses caused by the 1999 Super Cyclonic Storm in the study site.
II. Map socio-economic, environmental and infrastructural development changes through time in the study site and identify hotspots/coldspots.
III. Estimate differential post-disaster recovery rates, identify recovery hotspots/coldspots, and compare them with socio-economic, environmental and infrastructural development hotspots/coldspots.
IV. Compare and contrast community perceptions of socio-economic, environmental and infrastructural development changes and their implications for post-disaster recovery.

Key findings against the different research objectives and building up on each of them are presented below.

#### 8.1.1.1 Research objective 1

For the first time since SC 1999, this study compiled the most comprehensive review of socio-economic, environmental and infrastructural losses caused by the cyclone in the study site by means of a systematic review of literature.

Three main findings emerged from this review: i) for the first time, we were able to map land cover changes before and after the cyclone; ii) coastal districts were proven to be the most impacted, and iii) we now have an understanding, albeit partial, of the health impacts associated with the 1999 cyclone.

Firstly, thanks to advance in satellite remote sensing and the increasing availability of satellite imagery, land cover changes before and after the cyclone were mapped from earth observation through correlation with vegetation indexes, which contributed to downscaling the distribution of agricultural losses, otherwise only available at the District level from official data recorded in the immediate aftermath of the event.

Secondly, coastal districts were proven to be the worst impacted, particularly close to Paradeep. While this was expected and in line with experience from similar disaster events, it also showed in combination with evidence on agricultural losses that  the agricultural sector is highly vulnerable to these weather events, as demonstrated for the 1999 cyclone by Abhyankar, Patwardhan and Inamdar (2008, 2007, 2006a, 2006b) and Badola and Hussain (2005), while also being the primary source of livelihoods for the population in Odisha, where it contributes to less than 20% of Odisha's Gross State Domestic Product but employed 58% of the workforce in 2001, according to national census data.

Finally, this study contributes to mapping what we know about the health impacts associated with the 1999 event. Results from this review show a high incidence of post-traumatic stress disorder, ranging from 30.6% to 44.3% of the sampled population. This corresponds to the upper range of values of incidence of mental health disorders in the affected population in the first two years after a disaster, which can vary between 8.6% and 53% according to the literature (Alderman et al., 2012). Besides studies on post-traumatic stress disorder, however, there is a lack of evidence of other longer-term impacts (non-communicable diseases, malnutrition and birth outcomes) induced by the 1999 cyclone.

Limitations of this review include only considering literature in the English language and the fact that some literature, especially reports dating back to the time of occurrence of the cyclone, may not have been digitalised and may not be available online; these documents, however, were often cited as sources of information of retained papers.

While the systematic review contributes new knowledge to the understanding of the losses caused by SC 1999, the lack of official documentation of losses and of reporting systems emerges as a clear outcome of this review for the case of Odisha. This is in line with findings from other studies, notably with Ray-Bennett (2018), who concluded that the disaster management system in Odisha is not accountable, highlighting the need to put in place effective reporting mechanisms to ensure that losses are recorded. It shows that policy changes are required to promote accountability, facilitating the process of delivering immediate aid and supporting longer-term recovery after disasters, in line with international messaging and initiatives, notably the Sendai Framework Monitoring.

#### 8.1.1.2 Research objective 2

This research study then mapped socio-economic, environmental and infrastructural development changes through time in the study site (Kendrapara District of Odisha) and identified hotspots/coldspots.

A statistical analysis of socio-economic, environmental and infrastructural development changes during the period 2001-2011 was conducted using national census data in 660 villages across four Blocks of the Kendrapara District that were identified as being most exposed to tropical cyclones and related flooding: Rajnagar, Mahakalapad, Aali and Rajkanika.

As a result, 26 villages were identified as hotspots or coldspots of socio-economic, environmental and infrastructural development, having experienced the greatest degree of either positive (hotspots) or negative (coldspots) change relative to the full sample of 660 villages.

Census data were then further interrogated to identify key associates of socio-economic, environmental and infrastructural development in these mapped hotspots/coldspots.

Results showed that the three main associates of socio-economic, infrastructural and environmental development gains or losses were mostly pertinent to the spheres of i) communication; ii) infrastructure; and iii) gender, followed by other vulnerable groups.

These emerged as the top three drivers of mean socio-economic, environmental and infrastructural change. Moreover, improvements around communication, and in particular access to phone and to newspapers, were found to be one of the top five associates of development gains or losses in 85% of the hotspots/coldspots. This was followed by infrastructure, and specifically road type (paved versus mud), availability of public transport (bus/rail) and access to water, which was one of the top five associates of change in 77% of the hotspots/coldspots. Gender (including female literacy and female employment) was one of the top five associates in 65% of the hotspots/coldspots.

This is line with existing literature that demonstrated the correlation between phones and other communication attributes and the Human Development Index across Indian States, including Odisha (Bino Paul and Murti, 2016), as well as with studies that found that infrastructural development plays a key role in driving overall development (Goldschimdt & Kumar, 2016) and with the vulnerability literature (Adger, 2006). However, for the first time, the specific associates are mapped at the village level, contributing empirical evidence of drivers of development in the 26 identified hotspots/coldspots out of the 660 villages analysed.

Findings also showed that improvements in infrastructural conditions seem had the greatest impact on all other associates of change considered in the data-driven analysis across the communication, education, health, credit, social cohesion and livelihood diversification spheres. This is line with previous studies in other study sites that have found that interdependencies among critical infrastructural systems are a core issue in dealing with infrastructure-related disruptions during emergencies due to the cascade effects they are responsible for (Mendonça and Wallace, 2006.

The main limitations of the study relate to considering only post-cyclone datasets (2001 and 2011 census) due to the incomparability of other datasets (1991 census and 1998-99 National Health Survey), thus not looking at baseline development conditions, and to weighing of the different variables used to build a composite index of socio-economic, environmental and infrastructural development. Other approaches could be used in further studies to compare and contrast results. Similarly, the research could be extended beyond tropical cyclones to include other Blocks of the Kendrapara District most exposed to other types of natural hazards. The use of mixed methods for subsequent pieces of the analysis aims to overcome some of the limitations of single methods.

The findings from this study characterise, for the first time in the study area and period, the key associates of socio-economic, environmental and infrastructural development and their spatial distribution, contributing evidence to the literature of the key factors driving gains and losses. There is a potential for replication in the remaining Block of the Kendrapara District as well as in other areas of India to evidence spatial and temporal development gains and losses that can help direct interventions accordingly.

#### 8.1.1.3 Research objective 3

Post-disaster recovery rates were estimated using rice crop yied as a proxy, recovery hotspots/coldspots were mapped and post-disaster recovery was characterised in the 26 socio-economic, environmental and infrastructural development hotspots/coldspots that were previously identified as a contribution to research objective 2.

After removal of data gaps, the analysis was run for 627 out of the 660 villages considered for the statistical analysis of census data. The spatial and temporal distribution of recovery hotspots/coldspots was mapped as presented in Chapter 6. Further analysis was then conducted to specifically look at post-disaster recovery trends and patterns in the 26 hotspots/coldspots of socio-economic, environmental and infrastructural development.

Four main findings arose from this study: i) most of the villages considered in this study experienced post-disaster (2000-2006) mean rice crop yield rates at least equivalent to pre-disaster mean baseline rates (1991-1997); ii) there seems to be, however, a declining trend in rice crop yield in years subsequent to SC 1999 as opposed to an increasing trend in years before SC 1999; iii) crop yield rates have further dropped in the face of subsequent natural hazards, hampering any recovery that might have been previously achieved; and iv) villages that have experienced development gains have bounced back and forward faster than villages that have experienced development losses during the study period.

The literature shows that post-disaster harvest rates can either be lower or higher than pre-disaster baselines, depending on the magnitude of the event, the stage in crop development and on post-disaster interventions to support early recovery (Lansigan, De Los Santos, & Coladilla, 2000), with this study contributing empirical evidence of what this looks like in practice in cyclone-prone areas of Odisha.

The results also highlight that cyclones can have long-term adverse effects on agriculture and related livelihoods, as demonstrated by Duncan et al. (2017) for Odisha, and points to the potential for studies like this one to support in screening agricultural production changes to understand which areas have been left behind (J. M. A. Duncan, Dash, & Atkinson, 2015).

The results back up findings from the statistical analysis of census data, characterising the relationship between socio-economic, environmental and infrastructural development and post-disaster recovery rates in the 26 hotspots/coldspots of development. They show that hotspots of positive development change have recovered faster, with mean crop yield bouncing forward to 142% of pre-disaster values in 2000-2001 (likely because of post-disaster interventions), then dropping to 102% of pre-disaster values in 2004-2005 (showing continued recovery, in spite of a setback from 2000-2001), prior to bouncing forward to 132% of pre-disaster values in 2008-2009. Overall, the mean crop yield during the period 2000-2006 was 131% of the pre-disaster 1991-1997 mean values. On the contrary, the mean crop yield in coldspots of negative development change have taken longer to recover, with an initial bounce to 133% of pre-disaster recovery rates in 2000-2001, followed by a drop to 99% in 2004-2005 (showing that they had not recovered) and then a bounce forward to 133% in 2008-2009. Overall, the mean crop yield during the period 2000-2006 was only 99% of the pre-disaster 1991-1997 mean values, evidencing that full recovery had not yet occurred.

One of the main limitations of the study is that it considers only crop yield, while other features of crop production which have been proven to also be influenced by weather-related hazards could also be considered (Iizumi & Ramankutty, 2015). This notably includes the extent of cropping area (e.g., changes in arable land due to salinity intrusion and other factors directly associated with cyclones) and cropping intensity as it relates to multiple cropping seasons during a year (i.e., extending the study to rabi) (ibid.). The study could also be expanded to include other proxies depending on data availability.

The method has the potential for scaling up across coastal areas of India where agriculture is the main source of livelihood and can help in screening differential post-disaster recovery from freely available satellite images to understand which areas may have been left behind, requiring targeted interventions. It has the potential for replication in other areas of the world too and is particularly suitable for locations facing severe limitations on data availability.

It shows the great potential of satellite remote sensing to harness the data revolution and deliver on the 2030 Agenda. Applications to post-disaster recovery have been limited so far, with most remote sensing research studies focusing on short-term disaster damage assessment and recovery still remaining an understudied phase of the disaster risk management cycle (Aldrich, 2016; Cretney, 2017; Ghaffarian et al., 2018; G. Smith et al., 2018).

#### 8.1.1.4 Research objective 4

This research study then compared and contrasted community perceptions of socio-economic, environmental and infrastructural development changes and their implications for post-disaster recovery.

Fieldwork was conducted in six villages to verify findings from quantitative evidence. Of these, two were hotspots and two were coldspots of socio-economic, environmental and infrastructural development, sampled from the 26 hotspots/coldspots identified from the statistical analysis of census data. The remaining two villages had not emerged as being hospots/coldspots, thus experiencing mean change.

Results from the fieldwork confirmed findings from the quantitative analysis for the six villages selected for fieldwork. At the same time, however, they also evidenced some of the elements that were perceived by local communities as associates of development having a strong impact on post-disaster recovery that were not computed in the quantitative analysis as they are not captured by census data, notably as they pertain to the institutional sphere. This confirms the importance of conducting fieldwork and consulting with local communities to gather a more comprehensive and holistic understanding of reality.

While the findings from the qualitative verification of quantitative evidence cannot be considered as representative of the whole sample of 660 villages analysed, they offer practical evidence of the perceived attributes of development and their perceived relationship with post-disaster recovery in the six villages visited.

### 8.1.2 Theoretical contribution

In the face of the climate emergency, humanity is confronted with unprecedented challenges (IPCC, 2018; United Nations, 2016b). The SDGs and the Sendai Framework call governments worldwide to substantially step up national efforts to achieve transformational change. To support monitoring of these efforts, the United Nations has defined a set of indicators for both the SDGs and the Sendai Framework, which directly feed one another (UNISDR, 2018; United Nations, 2017). To effectively support the implementation of the global agenda and transition into a world where all needs are met and people live in safe, disaster-resilient and inclusive societies, an evidence base of which factors are correlated with disaster risk reduction, sustainable development and a combination of both is required to drive evidence-based policy (UNISDR, 2018; United Nations, 2014; Watmough et al., 2019; Weichselgartner & Kelman, 2015).

This thesis makes several contributions to the literature. First, to the author's knowledge, this is the first study to quantitatively analyse over ten years of recovery patterns following SC 1999 and in the face of subsequent natural hazards in Odisha, India.

Some researchers have estimated agricultural and other vegetation losses caused by the cyclone by comparing satellite images before and after. Results from a systematic review of scientific and grey literature presented in Chapter 4 show that this is true for seven studies (Abhyankar, Patwardhan and Inamdar, 2008, 2007, 2006a, 2006b; Mohanty et al., 2008; Abhyankar, Patwardhan and Inamdar, 206a, 2006b; Kundu et al., 2001; Nayak, Sarangi and Rajawat, 2001). However, none have extended the investigation to understanding long-term recovery patterns further to those losses.

Secondly, this is also the first piece of research to comprehensively quantify long-term socio-economic, environmental and infrastructural changes and identify the factors that may have accelerated or retarded recovery from SC 1999 in Odisha, India. Chapter 5 uses a data-driven approach to the selection of socio-economic, environmental and infrastructural variables of change. A correlation analysis is run to retain independent parameters only and results of a change detection analysis show that infrastructure and communication are the main attributes of change, whether positive or negative, over the study period in the study site. Chapter 6 builds on these results to quantify speed of recovery and derive hotspots and coldspots of recovery. Chapter 7 finally brings quantitative evidence together by gathering community perceptions to verify results of the previous analysis and identifies social cohesion as one of the key attributes of speed of recovery, in addition to infrastructure and communication. Findings appear to be consistent across the different bits of the research and different research methods, with qualitative and quantitative evidence very closely aligned. This allows us to conclude that infrastructure, communication and social cohesion are the three main attributes of speed of recovery from SC 1999 and in the face of subsequent natural hazards in the study site.

Some studies have previously investigated the individual relationship between post-disaster recovery and specific factors, including infrastructure (A. Deshmukh & Hastak, 2014; Miao, 2016; Vugrin & Camphouse, 2011) and social capital (Aldrich, 2011, 2016). For example, Deshmukh (2014) found infrastructure to be fundamental for post-disaster recovery, 'serving as the backbone of any community' (A. Deshmukh & Hastak, 2014, p. 6). Aldrich (2016), on the other hand, argues that most literature around speed of recovery only focuses on infrastructure and a few other attributes such as financial capabilities, driving the policy agenda accordingly, while the relationship between recovery rates and social capital is overlooked. In the case of communication, previous studies have predominantly focused on its links with either disaster preparedness (i.e., risk communication) (David E Alexander, 2014; Mileti & O'Brien, 1992) or emergency management (i.e., restoring access to communication in the immediate aftermath of an emergency to enable response) (Reddick, 2011). Not much has been said on the direct relationship between communication and post-disaster recovery. All of these studies, however, are sectoral and do not investigate broader patterns of recovery across multiple factors.

Other studies have adopted a more comprehensive approach to build frameworks that aim to assess post-disaster recovery by building indices that combine various factors which may play a role in accelerating or reducing speed of recovery (Brown et al., 2008; Bruneau et al., 2003; C.G. Burton, 2014; Christopher G Burton, 2012; Cutter et al., 2008). However, these studies primarily rely on a subjective selection of variables attributable to development to build indices as proxies for recovery, based on assumptions of positive or negative correlation without further investigation (Aldrich, 2016; Weichselgartner & Kelman, 2015). None have sought to connect broader recovery patterns to multiple, specific factors in Odisha, India.

Evidence from this study contributes to enhancing our understanding of key associates of speed of post-disaster recovery and brings clear practical and policy implications for focused interventions.

### 8.1.3 Methodological contribution

The 2030 agenda and the Sendai Framework set ambitious global goals and targets. Monitoring and reporting on progress is fundamental towards their achievement (UNISDR, 2018; United Nations, 2017). National reporting systems traditionally relying primarily on resource-intensive data collection methods such as national census and household surveys, however, appear to be outdated to capture change in a rapidly evolving landscape (Jacob, 2017; United Nations, 2014).

On the one hand, there is an urgency to step up monitoring and reporting efforts to ensure that actions are targeted to those in need, monitored and evaluated (Jacob, 2017; United Nations, 2014). On the other hand, the data revolution that we have experienced over recent decades has given us access to more data than ever before. This offers unprecedented opportunities for quicker and finer generation of knowledge from data (United Nations, 2014). New methods that harvest the best of both worlds are required to support progress monitoring and the ultimate delivery of the 2030 global agenda. The method developed in this study can support these efforts.

As described in Chapter 3, this research is shaped by pragmatism, translated into the adoption of a data-driven approach and the use of mixed methods. This study brought together different qualitative and quantitative research methods to harvest all available information and best answer the research questions. This approach is innovative in the field of post-disaster recovery studies: as evidenced in Chapters 2 and 4, existing literature on the topic have primarily focused on the use of single methods. Other literature focusing on the use of mixed methods has been most applied to other fields, notably agriculture, rural livelihoods and urban planning, but not to recovery studies.

Combining different research methods allowed the researcher to complement the strengths and overcome the weaknesses of the individual research methods used (Creswell, 2014). Quantitative methods for evaluating post-disaster recovery have been criticised for failing to capture the perspectives of the communities directly affected by disasters (Weichselgartner & Kelman, 2015). They also do not properly address elements that cannot be quantified, such as social cohesion (Aldrich, 2016). On the other hand, qualitative evidence is often associated with small-scale field studies which are not statistically representative and are often confined by access, time and financial constraints (Creswell, 2014). Satellite remote sensing paved the way for going beyond these limitations; however, community verification remains a key step towards accuracy and inclusiveness. In this thesis, the use of mixed methods helped in closing the scale gap and bridging the qualitative and quantitative divide.

What has been defined by Creswell (2014) as a "concurrent transformative" strategy has been applied for the concurrent investigation of change and recovery rates in the study area using different quantitative methods (statistical analysis and remote sensing). This allows the researcher to answer the research questions at different levels of analysis. A "sequential explanatory" strategy was then adopted to verify quantitative findings in the field using qualitative social research methods. This strategy uses qualitative findings to contribute to explaining quantitative evidence (Creswell, 2014).

The method proved to perform well, with quantitative evidence of change and its linkages with post-disaster recovery matching qualitative evidence from fieldwork. While verification of findings with communities could only take place in a limited number of villages, which cannot constitute a representative sample, findings only contributed to demonstrate that the methodology can be a valid screening tool to mine large datasets with a wide geographic extent over considerably long periods of time.

This presents numerous advantages, notably for applications in data-poor contexts, where official records may need to be complemented by remotely sensed information, but also in least developed areas where access may be a constraint (Devarajan, 2013). It is a low-cost method, which can be performed remotely using freely available datasets and which can help in targeting interventions by identifying priority areas that require further investigation on site. With more and more volunteered geographic information becoming available and an increasing involvement of citizens in science, there is potential to make use of crowdsourcing to generate additional information, verify satellite remote sensing data and contribute to large-scale investigations harvesting the power of big data and new technologies (Fritz et al., 2009; Haklay, 2013; H. Li et al., 2018; United Nations, 2014). Finally, there is potential for replication to support other disciplines as well, beyond natural hazards.

### 8.1.4 Empirical contribution / limitation of methods

This research offers an empirical contribution in using satellite remote sensing techniques for estimating the spatial and temporal distribution of crop yield as a proxy for post-disaster recovery in an area that is predominantly agricultural.

As described in Chapter 6, official Block-level crop yield records over a period of ten years were used to determine the statistical correlation between crop yield and the Normalized Difference Vegetation Index (NDVI), which is closely related to the vegetation greenness. Once the correlation established, the spatial and temporal distribution of crop yield at the village level was derived from NDVI. This helped in estimating yield at a smaller administrative unit (i.e., village level) than that for which official records were available (i.e., Block level). It also allowed for extending the study period beyond the dates for which official crop yield records were available.

NDVI has been used as a proxy measure of crop yields, at the peak of crop development, since the 1980's (Lopresti, Di Bella and Degioanni, 2015). NDVI has also been used as a proxy for ecosystem degradation (Huixia Li, Wei, & Zhou, 2015), site productivity (Nijland et al., 2015), land use change (Anyamba & Tucker, 2005) and climate variability or seasonality trends (de Jong, de Bruin, de Wit, Schaepman, & Dent, 2011; Kaufmann et al., 2003), among others.

When it comes to disasters, a systematic review of remote sensing-based proxies by Ghaffarian (2018) found that most proxies pertain to damage assessment in built-up environments, while a gap existed for proxies of recovery.  While the review purposely focused on urban areas, the keywords used did not include any reference to this so as to capture the natural environment as well (Ghaffarian et al., 2018). Findings from this review show that less than 30 papers out of the 114 reviewed focused on vegetation proxies for recovery. Furthermore, only Platt, Brown & Hughes (2016) identified crops as a proxy for livelihood recovery, albeit they offer an overview of methods for measuring recovery without any practical application (Ghaffarian et al., 2018).

Overall, the majority of studies looking at the interaction between vegetation and post-disaster recovery focus on post-fire recovery (Goetz, Fiske, & Bunn, 2006; João, João, Bruno, & João, 2018; Kinoshita & Hogue, 2011). In the case of tropical cyclones, the relationship with vegetation damage has been investigated, for example, for Hurricane Rita which hit Louisiana in 2006: however, this was mainly done as a measure of impact rather than recovery (Griffith, Chun, Millones, Parmentier, & Hamilton, 2019). Similarly, Curran, Dash & Llewellyn (2007) investigated the impacts of the Indian Ocean tsunami on coastal vegetation. No such studies have been previously conducted in Odisha, India.

As described in Chapter 2, rice constitutes about 90% of the total agricultural production in Odisha, India (Government of Odisha, 2011). This is by far the main source of livelihoods. It is, therefore, argued that crop yield can be seen as a measure of post-disaster recovery, whereby recovery is considered achieved when returning to yield values that are at least equal to, if not higher, than pre-disaster baselines. This is line with proxies for post-disaster recovery mapped in the literature (Joyce et al., 2009), with findings from the literature that have shown that the large majority of studies linking satellite earth observation with social outcomes have been successful at doing so applying single proxies (Heargreaves and Watmough, 2021), and with results from the scoping fieldwork conducted at the early stages of the thesis which confirmed the dominance of agriculture as the main source of livelihood in the study area and its perceived importance by local communities for driving post-disaster recovery.

This approach is suitable only for application in areas where agriculture is the main economic activity. This contribution paves the way for replication in other study sites, particularly in those areas like Odisha where the lack of recorded data hampered any previous understanding of recovery patterns. The study can also be expanded to cover other types of crops, such as vegetable farming or other cash crops (cf. Stone, 2009). Similarly, it can also be extended to other attributes of crop production like the extent of cropping area (e.g., changes in arable land due to salinity intrusion and other factors directly associated with cyclones) and cropping intensity as it relates to multiple cropping seasons during a year (i.e., extending the study to *rabi*) (Iizumi & Ramankutty, 2015).

The combination of the remote sensing analysis with an investigation of the socio-economic, infrastructural and environmental changes in the study site allowed for a combined understanding of the main attributes of recovery. The adoption of a data-driven approach helped in overcoming some of the bias of subjective reasoning; at the same time, however, this implied that the research primarily considered physical features, with other attributes, such as those pertaining to psychological health, only partially captured through the systematic review and qualitative research. The research also does not consider the influence of policy changes over physical changes, which could be further investigated.

## 8.2 Policy recommendations

### 8.2.1 Policies to strengthen infrastructure, communication and social cohesion

This research brings clear policy implications. It shows that infrastructure, communication and social cohesion are primary associates of post-disaster recovery; these factors should, therefore, be reflected in policy and significant investments should be made in these areas.

#### 8.2.1.1 Local and national policies

At the local level, major infrastructural improvements have been made over the years in the aftermath of SC 1999, with investments in flood protective infrastructure and overall infrastructural development, as also captured by this study. Yet, findings from fieldwork demonstrated that communities were not involved in planning, nor were they employed to contribute to building infrastructure under existing government schemes. Community-driven initiatives, such as orienting village funds towards building a livestock shed at the base of the cyclone shelter in Daruora, demonstrate the value of collective action but also highlights the shortcomings of infrastructural development initiatives that do not take into account the perspectives of beneficiaries. Existing poverty alleviation schemes such as NREGA (cf. section 2.6.4 of this report) offer an opportunity to generate co-benefits by employing community members in disaster-prone areas to build infrastructural assets (e.g., roads, canals, water wells, etc.). While the programme targets unskilled labour, opportunities should be explored to strengthen community engagement in planning and building key infrastructural assets that can help enhance post-disaster recovery. Furthermore, the Indira Awaas Yojana programme, which aims to support the construction of houses in rural societies, should be revised to ensure it is accessible to everyone in need; in its current form, it is *de facto* inaccessible to those who cannot afford to anticipate costs to be then recovered through the scheme. Other international development projects, such as the World Bank's Disaster Recovery Project[9], have a strong focus on infrastructural development, with community participation as one of its key elements. Focusing only on infrastructure for recovery, however, may not be sufficient if other fundamental associates of recovery such as communication and social cohesion are not fostered.

Access to information has improved thanks to enhanced availability of mobile phones and television. However, findings from fieldwork showed that communities relied on commercial sources for lifesaving information; while official alerting systems were in place, these were only partially known and not equally accessible to the population. The effectiveness of communication systems, therefore, appeared to be associated with household-driven initiatives. More systematic investments in avenues for official communication of risk information, dissemination of warnings and access to telecommunications during emergency, therefore, appear to be required. This is in line with international recommendations on advancing policies and practices to bridge the "last mile" by reaching all communities, including the most remote, with timely, authoritative and actionable disaster information (Luther et al., 2017).

Finally, most of the literature on speed of recovery primarily looks at economic and/or infrastructural damage, with policy approaches shaped thereafter (Aldrich, 2016). This thesis, however, shows that alternative policy approaches should focus on building social cohesion and

[9] https://projects.worldbank.org/en/projects-operations/project-detail/P148868?lang=en

local capacities. There is potential to more closely link different poverty alleviation schemes and to bring in a community dimension to those.

#### 8.2.1.2 Global agenda

Both the SDGs and the Sendai Framework recognise the importance of investing in infrastructure and communication (UNISDR, 2015b; United Nations, 2015c). When it comes to social cohesion, both frameworks capture well the need for “inclusion” to advance the sustainable development and disaster risk reduction agendas; however, they both fail to explicitly hint at the nuance of “cohesion”. Interestingly, “cohesion” is not defined in the United Nations disaster risk reduction terminology either (United Nations, 2016c).

SDG 9: ‘Build resilient infrastructure, promote sustainable industrialization and foster innovation’ acknowledges that, while they remain scarce in developing countries, basic infrastructure as well as information and communication technologies are fundamental for sustainable development (United Nations, 2015c). SDG 11: ‘Make cities inclusive, safe, resilient and sustainable’ further recognises the right of all to adequate, safe and affordable housing and basic services (ibid.).

The SDGs also call for the social, economic and political “inclusion” of all, and for enhanced representation, under SDG 10: ‘Reduce inequality within and among countries’. SDG 11 flags the requirement to substantially increase the number of municipalities with policies in place to promote “inclusion”, as well as disaster risk management in line with the Sendai Framework (ibid.).

Similarly, the Sendai Framework identifies the need to substantially decrease critical infrastructure losses as one of its seven targets, which translates into a requirement to incorporate risk considerations in ‘publicly owned, managed or regulated’ infrastructure (UNISDR, 2015b), as well as to provide incentives for private actions as required. The concept of building back better is also reflected in one of four priorities for action. The framework further calls for specific disaster communication policies and “inclusive” decision-making (ibid.).

None of the two frameworks includes any specific mention to “cohesion” or a similarly defined concept. The Cambridge Dictionary (*Cambridge Advanced Learner’s Dictionary & Thesaurus*, 2013) defines “cohesion” as the state of ‘being in close agreement and working well together’; “inclusion”, on the other hand, is defined as ‘the act of including someone or something as part of a group, list, etc., or a person or thing that is included’ (bid.). The element of not only including communities in decision-making, but also ensuring that, within those communities, people are in close agreement and work well together does not come out explicitly as a key element to foster disaster risk reduction and sustainable development in the international frameworks of reference. As a consequence, the push for national policies and plans that promote enhanced social cohesion is not apparent from the frameworks and is identified as a policy gap emerging from findings of this research.

### 8.2.2 Systematic recording and reporting of disaster losses

This research found that, twenty years after SC 1999, no baseline data of losses was available at any scale smaller than the district level.

The United Nations developed sets of indicators to monitor progress against both the SDGs (UN, 2019) and the Sendai Framework (United Nations, 2016c). These have been linked so that the Sendai Framework indicators effectively contribute to measuring some of the corresponding SDG indicators. In 2018, the United Nations then launched the Sendai Framework Monitor, an online tool aimed at capturing progress towards achievement of the Sendai Framework's and related SDG's targets. To support data collection and analysis, the Sendai version of DesInventar, a widely-used tool for disaster information management and the generation of national disaster inventories (Groeve & Poljansek, 2013), was developed as a global disaster loss database. These represent historic efforts to move forward on disaster loss data collection and build on the work of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts, established in 2013 to promote advances in loss and damage estimation associated with the adverse effects of climate change.

The starting point for these international efforts is the acknowledgement that we cannot measure what we do not know. Recoding disaster losses is essential to target interventions and monitor post-disaster recovery. Despite these recent advances on international policy, however, the development of national disaster loss databases and the systematic recording of reliable loss information at fine scale continue to be underdeveloped, particularly in developing countries (Groeve & Poljansek, 2013). Other global datasets such as EM-DAT remain a reference for overcoming the lack of official national data (Groeve & Poljansek, 2013).

While policy changes are being promoted at the international level, national governments have to step these efforts up to enhance reporting. India, in particular, has not reported any data as a contribution to the Sendai Framework Monitor. Odisha has the merit of being the only state of India for which information is available on DesInventar; however, reporting is still very limited, with less than 25% of required information provided. Changes in national policies are required to comply with recommended international standards for recording and reporting of disaster losses.

### 8.2.3 Investment in methods to calculate post-disaster recovery

At the international level, the Post-Disaster Needs Assessment (PDNA) methodology represents the standard approach for the rapid analysis of needs after a disaster to inform recovery efforts. The PDNA tool was developed by the UN Development Group, the World Bank and the European Union as a harmonized and coordinated effort to support nationally-led assessments of recovery needs (Bollin & Khanna, 2007; UNDP, 2013b). A PDNA aims to assess the full extent of the impact of a disaster in a multi-sectoral manner to ultimately inform the development of an actionable recovery strategy (UNDP, 2013b).

One of the key features of the PDNA methodology is its strong focus on quantifying the economic value of the effects of a disaster, to support resource mobilisation for recovery. It will look, for instance, at estimating the quantity of debris that has been generated by a disaster based on the number of collapses buildings, fallen trees, etc. and at deriving a cost tag for managing that rubble. This will be considered as the economic value of the effects of that disaster as they pertain to disaster waste management.

The PDNA is initiated after the immediate emergency response phase of a disaster, which focuses on life-saving interventions for which flash appeals may be issued, but as soon as possible before the window of opportunity to influence early recovery is lost (UNDP, 2013b). The PDNA exercise usually lasts between four and six weeks, depending on the magnitude of the disaster and the extent of damage. Given the pressing timeframes in a post-disaster situation, it is important to have pre-defined methods to assess losses and recovery needs across the different sectors covered by the PDNA. At the same time, the lack of a systematic collection of baseline data in many of the countries which will typically request international assistance combined with time constraints most often implies reliance on qualitative research methods such as key informant interviews and community-based discussions to gather an understanding of key recovery needs (UNDP, 2013a). This information may complement any existing national baseline data and/or common operational datasets that may be maintained by United Nations Country Offices, when available.

The strong push on reporting of disaster information that has only been consolidated over most recent years paves the way for further integration of global databases that can support rapid access to information in the aftermath of a disaster. In addition, there is potential for strengthening the use of remote sensing techniques to make use of freely available information and convert it into actionable knowledge that can inform decision-making in emergency situations.

In the era of big data, when spatial visualization tools have made geospatial information easy to access and understand for everyone, investments should be made in methods that can support post-disaster recovery assessment making use of data-driven approaches such as the one proposed in this thesis. This can help overcome some of the limitations of tools that require extensive fieldwork in short periods of time, with constraints on time as well as human and financial resources. There is potential to develop screening tools for application as part of existing, well-defined international standards for post-disaster needs assessment.

At the same time, these efforts should also be pursued at the national level, to develop and/or adopt tools that can support nationally-led efforts while aligning with international standards and supporting global reporting.

This will also contribute to parallel efforts in pushing the global disaster resilience agenda forward. The United Nations Making Cities Resilient Campaign, for example, promotes self-assessment of disaster resilience by city governments, with expedite recovery and build back better as one of ten essentials for disaster resilience, with related indicators (UNISDR, 2017; United Nations Office for Disaster Risk Reduction (UNISDR), 2017).

## 8.3 Future research

Four main sets of research questions have emerged as ideas for future investigation:

- Infrastructure, communication and social cohesion as key attributes of post-disaster recovery. How do they interact?
- How can non-physical attributes, such as those related to mental health, help detect a relationship between development changes and post-disaster recovery?
- Emerging areas of research: mixed methods for development studies/post-disaster recovery. How can the relationship between socio-economic, environmental and infrastructural development and post-disaster recovery be characterised in urban contexts?
- How can the relationship between socio-economic, environmental and infrastructural development and post-disaster recovery be characterised when expanding the analysis domain to areas exposed to other types of hazards than tropical cyclones and related flooding?

# Appendices

**A.1 – Systematic review: list of papers**

**A.2 – Systematic review: detailed losses by type**

**A.3 – Data-driven analysis of census data: correlation analysis**

**A.4 – List of interviewed key informants**

**A.5 – Ethics forms, Participant Information Sheets and Consent Forms**

## A.1 Systematic review: list of papers

**Excluded papers (by year of publication)**

| ID | Author(s) | Year | Title | Publisher | Reason for exclusion |
|---|---|---|---|---|---|
| 1 | Pal, Ghosh and Ghosh | 2017 | Institutional framework and administrative systems for effective disaster risk governance - Perspectives of 2013 Cyclone Phailin in India | International Journal of Disaster Risk Reduction | Focus on 2013 cyclone Phailin |
| 2 | Mishra | 2017 | Socio-economic Impacts of Climate Change in Odisha: Issues, Challenges and Policy Options | Journal of Climate Change | Not discussing losses from 1999 cyclone |
| 3 | Jha, Basu and Basu | 2016 | Studying Policy Changes in Disaster Management in India: A Tale of Two Cyclones | Disaster Medicine and Public Health | Focus on the effect of policy changes after 1999 |
| 4 | Iwasaki | 2016 | Linking disaster management to livelihood security against tropical cyclones: A case study on Odisha state in India | International Journal of Disaster Risk Reduction | Focus on changes after 1999 and their impact during subsequent cyclones |
| 5 | Kulkarni, Somasundaram and Tripathy | 2016 | Sea wall embankment at Pentha, Odisha - An Indian experience on sea shore protection using geotextile tubes | Water and Energy International | Focus on protection measures built well after the 1999 cyclone |

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| 6 | Sharma et al. | 2016 | Spatial Verification of Rainfall Forecasts During Tropical Cyclone 'Phailin' | Tropical Cyclone Activity over the North Indian Ocean | Focus on 2013 cyclone Phailin |
| 7 | Mohapatra | 2016 | Monitoring and Forecasting of Tropical Cyclones over North Indian Ocean | Advanced Numerical Modeling and Data Assimilation Techniques for Tropical Cyclone Prediction | Focus on cyclone forecasting |
| 8 | Mariaselvam and Gopichandran | 2016 | The Chennai floods of 2015: urgent need for ethical disaster management guidelines | Indian Journal of Medical Ethics | Focus on 2015 Chennai floods |
| 9 | Bahinipati and Patnaik | 2015 | The damages from climatic extremes in India: do disaster-specific and generic adaptation measures matter? | Environmental Economics and Policy Studies | Focus on changes that occurred after 1999 and their impact during subsequent cyclones |
| 10 | Mohanty et al. | 2015 | A Great Escape from the Bay of Bengal "Super Sapphire–Phailin" Tropical Cyclone: A Case of Improved Weather Forecast and Societal Response for Disaster Mitigation | Earth Interactions | Focus on 2013 cyclone Phailin |

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| 11 | Sandhu and Das | 2014 | Role of exotic vegetation in coastal protection: An investigation into the ecosystem services of Casuarina in Odisha | Economic and Political Weekly | Focus on ecosystem services |
| 12 | Rao and Srinivas | 2014 | Multi-Physics ensemble prediction of tropical cyclone movement over Bay of Bengal | Natural Hazards | Focus on cyclone forecasting |
| 13 | Chhotray | 2014 | Disaster relief and the Indian state: Lessons for just citizenship | Geoforum | No data on losses |
| 14 | Dube, Poulose and Rao | 2013 | Numerical simulation of storm surge associated with severe cyclonic storms in the Bay of Bengal during 2008-11 | MAUSAM | Refers to 2008-11 |
| 15 | Dash | 2013 | How Odisha Managed the Phailin Disaster | Economic and Political Weekly | Focus on 2013 cyclone Phailin |
| 16 | Datta et al. | 2013 | Seasonal variation of methane flux from coastal saline rice field with the application of different organic manures | Atmospheric Environment | Not studying direct links with 1999 cyclone |
| 17 | Das and Crepin | 2013 | Mangroves can provide protection against wind damage during storms | Estuarine, Coastal and Shelf Science | Focus on ecosystem services |
| 18 | Abhyankar, Patwardhan and Inamdar | 2012 | Estimation of flooded areas due to supercyclone using | 33rd Asian Conference on | Focus on inundation areas |

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| | | | Radarsat-1 SAR data and discriminant approach - An Indian case study | Remote Sensing 2012 | |
| 19 | Wang, Han and Sriver | 2012 | Impact of tropical cyclones on the ocean heat budget in the Bay of Bengal during 1999: 1. Model configuration and evaluation | Journal of Geophysical Research: Oceans | Focus on ocean heat budget |
| 20 | Deshpande, Pattnaik and Salvekar | 2012 | Impact of cloud parameterization on the numerical simulation of a super cyclone | Annales Geophysicae | Focus on numerical modelling |
| 21 | Singh et al. | 2011 | Assimilation of the multisatellite data into the WRF model for track and intensity simulation of the Indian Ocean tropical cyclones | Meteorology and Atmospheric Physics | Focus on numerical modelling |
| 22 | Das | 2011 | Examining the storm protection services of mangroves of Orissa during the 1999 Cyclone | Economic and Political Weekly | Focus on ecosystem services |
| 23 | Ray-Bennett | 2010 | The role of microcredit in reducing women's vulnerabilities to multiple disasters | Disasters | Focus on microcredit for recovery |
| 24 | Dube et al. | 2009 | Storm surge modelling for the Bay of Bengal and Arabian Sea | Natural Hazards | Focus on numerical modelling |

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| 25 | Rao, Prasad and Srinivas | 2009 | Impact of horizontal resolution and the advantages of the nested domains approach in the prediction of tropical cyclone intensification and movement | Journal of Geophysical Research: Atmospheres | Focus on cyclone forecasting |
| 26 | Ray-Bennett | 2009 | Coping with multiple disasters and diminishing livelihood resources caste, class, and gender perspectives: The case from Orissa, India | Regional Development Dialogue | No data on losses |
| 27 | Ray-Bennett | 2009 | The influence of caste, class and gender in surviving multiple disasters: A case study from Orissa, India | Environmental Hazards | No data on losses |
| 28 | Panigrahi | 2008 | Safer and high quality homes in Orissa | World Habitat | Focus on housing design |
| 29 | Sikka and Rao | 2008 | The use and performance of mesoscale models over the Indian region for two high-impact events | Natural Hazards | Focus on numerical modelling |
| 30 | Singh et al. | 2008 | The impact of variational assimilation of SSM/I and quickSCAT satellite observations on numerical simulation of | Weather and Forecasting | Focus on numerical modelling |

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| | | | Indian ocean tropical cyclones | | |
| 31 | Patnaik and Sivagnanam | 2008 | Cyclonic storm surge vulnerability of the coastal regions the case of periodic disasters of Orissa, India | 29th Asian Conference on Remote Sensing 2008 | No data on losses |
| 32 | Mohopatra and Mohanty | 2008 | Periodicity in intraseasonal variation of summer monsoon rainfall over Orissa, India in relation to synoptic disturbances | Meteorology and Atmospheric Physics | Focus on rainfall seasonal variations |
| 33 | Nghiem and Neumann | 2008 | Remote sensing of the global environment with satellite scatterometry | Proceedings of SPIE - The International Society for Optical Engineering | For Odisha, focus on flood extent |
| 34 | Sinha et al. | 2008 | Numerical modeling of tide-surge interaction along Orissa coast of India | Natural Hazards | Focus on numerical modelling |
| 35 | Revi | 2008 | Climate change risk: an adaptation and mitigation agenda for Indian cities | Environment and Urbanization | No data related to the 1999 cyclone |
| 36 | Mahapatra et al. | 2007 | Influence of coast line on upper ocean's response to the tropical cyclone | Geophysical Research Letters | Focus on numerical modelling |

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| 37 | Rao et al. | 2007 | Effect of estuarine flow on ocean circulation using a coupled coastal-bay estuarine model: an application to the 1999 Orissa cyclone | Natural Hazards | Focus on numerical modelling |
| 38 | Latha and Rao | 2007 | Surge simulations for 1999 Orissa super cyclone using a finite element model | Natural Hazards | Focus on numerical modelling |
| 39 | Mandal et al. | 2007 | Impact of sea surface temperature in modulating movement and intensity of tropical cyclones | Natural Hazards | Focus on numerical modelling |
| 40 | Kumar et al. | 2007 | Experimental superensemble forecasts of tropical cyclones over the Bay of Bengal | Natural Hazards | Focus on cyclone forecasting |
| 41 | Mukhopadhyay | 2007 | Aparajita Orissa | IUHPE – Promotion & Education | No data on losses, only on beneficiaries of implemented programmes |
| 42 | Patra et al. | 2007 | Atmospheric deposition and surface stratification as controls of contrasting chlorophyll abundance in the North Indian Ocean | Journal of Geophysical Research: Oceans | No data related to the 1999 cyclone |

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| 43 | Ali, Kishtawal and Jain | 2007 | Predicting cyclone tracks in the north Indian Ocean: An artificial neural network approach | Geophysical Research Letters | Focus on numerical modelling |
| 44 | Ray-Bennett | 2007 | Environmental disasters and disastrous policies: An overview from India | Social Policy and Administration | No data related to the 1999 cyclone |
| 45 | Mandal, Mohanty and Das | 2006 | Impact of satellite derived wind in mesoscale simulation of Orissa super cyclone | Indian Journal of Marine Sciences | Focus on numerical modelling |
| 46 | Varma et al. | 2006 | Study of geophysical parameters associated with the Orissa super cyclone using active and passive microwave remote sensing measurements | International Journal of Remote Sensing | Focus on hazard parametrisation |
| 47 | Wolanski | 2006 | Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees? | Proceedings of the Regional Technical Workshop, Khao Lak, Thailand 28-31 August 2006 | Not focused on the 1999 cyclone |
| 48 | Kalsi and Srivastava | 2006 | Characteristic features of Orissa super cyclone of 29th October , 1999 as observed through CDR Paradip | MAUSAM | Focus on hazard parametrisation |

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| 49 | Rautela | 2006 | Risk management for vibrant economic growth and sustained development | Disaster Prevention and Management | No data related to the 1999 cyclone |
| 50 | Venkatesh et al. | 2006 | Preliminary results on the simulation of the 1999 Orissa super cyclone using a GCM with a new boundary layer code | MAUSAM | Focus on numerical modelling |
| 51 | Jafar | 2005 | National capital of India: From ignorance towards preparedness | International Conference on Geotechnical Engineering for Disaster Mitigation & Rehabilitation | No data related to the 1999 cyclone |
| 52 | Rajesh et al. | 2005 | Observations on extreme meteorological and oceanographic parameters in Indian seas | Current Science | Focus on hazard parametrisation |
| 53 | Dube et al. | 2005 | Effect of the Mahanadi River on the development of storm surge along the Orissa coast of India: A numerical study | Pure and Applied Geophysics | Focus on hazard parametrisation |
| 54 | Das | 2005 | Environmental problem of drainage congestion in Mahanadi Delta, India: | World Water Congress 2005: Impacts of Global Climate | Focus on drainage |

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| | | | Case study of a remedial direct cut | Change - Proceedings of the 2005 World Water and Environmental Resources Congress | |
| 55 | Singh et al. | 2005 | Impact of bogus vortex for track and intensity prediction of tropical cyclone | Journal of Earth System Science | Focus on cyclone forecasting |
| 56 | Schultz, Russell and Espinel | 2005 | Epidemiology of tropical cyclones: The dynamics of disaster, disease, and development | Epidemiologic Reviews | No data related to the 1999 cyclone |
| 57 | Badola and Hussain | 2005 | Valuing ecosystem functions: An empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India | Environmental Conservation | Data on asset losses in 3 villages |
| 58 | Chittibabu et al. | 2004 | Mitigation of flooding and cyclone hazard in Orissa, India | Natural Hazards | Focus on hazard parametrisation |
| 59 | Narkhedkar et al. | 2004 | Orissa super cyclone of October 1999 as revealed by IRS-P4 satellite data | Indian Journal of Radio and Space Physics | Focus on hazard parametrisation |
| 60 | Dube et al. | 2004 | Numerical modelling of storm surge in the head Bay of Bengal using location specific model | Natural Hazards | Focus on numerical modelling |

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| 61 | Ghosh et al. | 2004 | Participatory water management for sustainable development in coastal belt of Orissa | Journal of Rural Development | Focus on the establishment of water user groups |
| 62 | Mohanty, Mandal and Raman | 2004 | Simulation of Orissa super cyclone (1999) using PSU/NCAR mesoscale model | Natural Hazards | Focus on numerical modelling |
| 63 | Hall and Lobina | 2004 | Private and public interests in water and energy | Natural Resources Forum | Not focused on the 1999 cyclone |
| 64 | Shanker, Pandav and Choudhury | 2004 | An assessment of the olive ridley turtle (Lepidochelys olivacea) nesting population in Orissa, India | Biological Conservation | Not focused on the 1999 cyclone |
| 65 | Kar et al. | 2003 | Analyses of Orissa super cyclone using TRMM (TMI), DMSP (SSM/I) and OceanSat-1 (MSMR) derived data | Global Atmosphere and Ocean System | Focus on hazard parametrisation |
| 66 | Vinayachandran and Mathew | 2003 | Phytoplankton bloom in the Bay of Bengal during the northeast monsoon and its intensification by cyclones | Geophysical Research Letters | Focus on enhanced biological production as a positive effect of the 1999 cyclone |
| 67 | Dash and Mohanty | 2002 | A study on the avian fauna in captivity at Nandankanan Zoological Park, Orissa | Zoos' Print Journal | No evidence of losses due to the 1999 cyclone |

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| 68 | Trivedi, Sanjay and Singh | 2002 | Numerical simulation of a super cyclonic storm, Orissa 1999: impact of initial conditions | Meteorological Applications | Focus on numerical modelling |
| 69 | Madhu et al. | 2002 | Enhanced biological production off Chennai triggered by October 1999 super cyclone (Orissa) | Current Science | Focus on enhanced biological production as a positive effect of the 1999 cyclone |
| 70 | Vatvani et al. | 2002 | Cyclone induced Storm Surge and Flood Forecasting System for India | Coastal Disaster Conference 2002 | Focus on numerical modelling |
| 71 | Juvva and Parikh | 2002 | From nowhere to care: Experiences with cyclone rehabilitation interventions | Indian Journal of Social Work | Focus on rehabilitation efforts |
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| 74 | Bhatia et al. | 2000 | USE OF METEOSAT-5 DERIVED WINDS FOR ANALYSIS OF TWO TROPICAL CYCLONES AFFECTING GUJARAT COAST ON 20 MAY, 1999 AND ORISSA COAST ON 29 OCTOBER, 1999 | Lorne, Australia, 28 February - 3 March 2000, Eumetsat proceedings EUMP-28 | Focus on numerical modelling |

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## A.2 Systematic review: detailed losses by type

**Research question 1: Which recorded losses did the 1999 Odisha cyclone cause?**

**Table of losses by type**

*Mortality*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 1 | Ray-Bennett | 2018 | 10,086 | Jagatsinghpu: 8119<br>Puri: 301<br>Cuttack: 456<br>Ganjam: 183<br>Other Districts: N/A (the study considers coastal Districts only) | | | Male disaster mortality higher than female disaster mortality (cumulated % available for 1999-2013).<br><br>Sources: reports, journals and census data from Odisha State Disaster Management Authority, Special Relief Organisation and Indian Meteorology Department/Odisha. |
| 2 | Irshad | 2017 | 9,885 | | | | |
| 5 | Patra and Jena | 2013 | 9,803 plus 40 missing (estimate 15,000) | | | | Highest mortality in the Ersama Block of Jagatsinghpur District |

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|---|---|---|---|---|---|---|---|
| 6 | Chhotray and Few | 2012 | Over 10,000 | | | Siyali hamlet of Sahadabedi village (Ersama Block of Jagatsinghpur District): 72 | More than 70% of victims drowned by surge. Ersama Block of Jagatsinghpur worst affected. |
| 8 | Das and Vincent | 2009 | Nearly 10,000 (70% drowned) | 256 victims in 409 villages in the Kendrapara District that were both affected by the cyclone and presented mangroves | | Village-level mortality data compiled but not published for the 409 villages analysed | Source (State-level mortality data): Gupta MC, Sharma VK (2000) Orissa Super Cyclone 99 (New United Press, New Delhi). |
| 14 | Das | 2007 | Nearly 10,000 | Kendrapara: 392 lives lost | | | |
| 18 | Kalsi | 2006 | 9,893 | Jagatsinghpur: 8,119 (worst affected district, mainly because of the surge induced havoc in the Ersama Block) | | | Sources: Government of Orissa, Indian Institute of Public Administration, New Delhi & Report of the Task Force on Repairs and Reconstruction of the Housing in the |

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|---|---|---|---|---|---|---|---|
| | | | | | | | Areas Affected by Super Cyclone in Orissa prepared by Ministry of Urban Development, Government of India. |
| 23 | Kar et al. | 2004 | Almost 20,000 | | | | Source: Juvva S., and Rajendran P. (2000) Disaster mental health Current perspective. Indian Journal of Social Work, 61, 4, 527-541. |
| 24 | Panigrahi | 2003 | 9,885 | | | | Source: White Paper on Super Cyclone in Orissa. Revenue Department, Government of Orissa, December 1999. |
| 27 | Chhotray et al. | 2002 | 81 deaths due to diarrhoea | | | | Source: Health Department, Government of Orissa |
| 28 | Das | 2001 | 9,574 | Puri: 301; Cuttack: 414; Kendrapara: 242; Nayagarh: 3; | | | As of 17/11/1999 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Khurda: 88; Bhadrak: 98; Keonjhar: 29; Dhenkanal: 51; Jagatsinghpur: 8,119; Jaipur: 172; Balasore: 49; Mayurbhanj:8. | | | |
| 32 | Government of Orissa | 1999 | 9,866 | Balasore: 49; Bhadrak: 98; Cuttack: 456; Dhenkanal: 51; Jagatsinghpur: 8,119; Jaipur: 188; Kendrapara: 469; Keonjhar: 31; Khurda: 91; Mayurbhanj: 10; Nayagarh: 3; Puri: 301. | | | |

*Physical injuries*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 2 | Irshad | 2017 | 7,505 | | | | Source: Evaluation study of Rehabilitation and Reconstruction Process in Post-Super Cyclone, Odisha |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5 | Patra and Jena | 2013 | 3,312 people injured | | | | Injuries mostly due to falling trees and collapsing walls |
| 18 | Kalsi | 2006 | 7,507 people injured | | | | |
| 24 | Panigrahi | 2003 | 2,507 human injuries | | | | Source: White Paper on Super Cyclone in Orissa. Revenue Department, Government of Orissa,<br>December 1999. |
| 28 | Das | 2001 | 2,265 people injured | Puri: 15; Cuttack: 1,594; Kendrapara: N/A; Nayagarh: N/A; Khurda: 201; Bhadrak: N/A; Keonjhar: N/A; Dhenkanal: N/A; Jagatsinghpur: N/A; Jaipur: 455; Balasore: N/A; Mayurbhanj: N/A. | | | |

*Other health impacts*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 5 | Patra and Jena | 2013 | | | | | Anxiety, depression and |

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|---|---|---|---|---|---|---|---|
| | | | | | | | abnormal behavioural patterns recorded up to 1 year after the cyclone (higher incidence in those who lost relatives), but lack of systematic reporting |
| 10 | Khuntia et al. | 2008 | Incidence of V. cholerae six month after the super cyclone was found significantly higher than the pre-cyclonic period (P < 0.5) | | | | Based on 198 samples collected from selected hospitalized patients |
| 15 | Kar et al. | 2007 | | Jagatsinghpur, Bhadrak and Kendrapara (as worst affected Districts and, thus, considered to be high exposure | | | Sample: 447 children and adolescents with an age range of 7–17 years across the study districts. |

| | | | | | | | |
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| | | | | areas): PTSD (post-traumatic stress disorder) in 30.6% of sampled population, with an additional 13.6% presenting sub-syndromal PTSD. Depression significantly associated with PTSD. | | | Factors influencing PTSD were found to be: high exposure, lower educational level and middle socioeconomic status. Other factors such as fear, perceived threat to life, death of family members, loss of home or stay in shelters were *not* found to be significantly associated with PTSD. |
| 23 | Kar et al. | 2004 | Jagatsinghpur (Olara village), Balasore (Kharasahapur and Anantapur villages), Bhadrak (Khaparapada and Lunia villages), Jajpur | | | Village-level disaggregated data not published. | Sample: '540 individuals (selected randomly from 3119 persons of 540 households) consisting of 327 males and 213 females with a mean age of 41.12 ± 15.1and |

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|---|---|---|---|---|---|---|---|
| | | | (Mallikapur village), Kendrapara (Pundalo village) and Khurda (Vanivihar and Badagada areas) Districts: 80.4% of sample had psychiatric morbidity; 44.3% prevalence of PTSD; 57.6% experienced anxiety disorders; and 52.8% were diagnosed with depression. | | | | 38.8 ± 13.8 years respectively. Out of this 403 persons were from the area of high exposure.' (p.230) |
| 25 | Sehgal, Sugunan and Vijayachari | 2002 | | | | 4 villages in the Jaipur District: 19.2% of sample with post-cyclone symptomatic leptospiral infection; in | Sample size: 142. Cf. paper n. 31 (same research team) |

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|---|---|---|---|---|---|---|---|
| | | | | | | addition, 8.5% of the sample with low levels of antibodies. | |
| 27 | Chhotray et al. | 2002 | 97,000 attacks and 81 deaths due to diarrhoea between 1 November and 1 December 1999.<br><br>72.3% out of a sample of 107 patients hospitalised for diarrhoea between 8 November and 8 December 1999 found to be positive to V. Cholera (53.03% males; 75.76% adults). | | | | Source (total number of attacks and related mortality): Health Department, Government of Orissa |
| 31 | World Health Organization | 2000 | | | | 4 villages in the Jaipur District | Sample size: 142 (44 from Tarakot; 40 from |

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|---|---|---|---|---|---|---|---|
| | | | | | | (Berunpur, Ranpur, Taharpur and Tarakot), served by the primary healthcare centre in Korai village: 15.5% cases of leptospirosis; 15.5% presumed cases; 8.5% previous exposure; 60.6% negative. | Taharpur; 29 from Barunpur; 16 from Ranpur; and 13 hospitalised from other villages). Total population of selected villages: 12,500.<br><br>Study conducted between 10 and 15 December 1999 (6 weeks after the cyclone and 4 weeks after the outbreak).<br><br>Cf. paper n. 25, same research team. |

*Total economic losses*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 2 | Irshad | 2017 | Rs. 7,258.2 million (1) | | | Loss of asset value (%) in 3 villages in the Ersama Block in the Jagatsinghpur District: Kuchila; Chaulia; and Ajanganbedi. (2) | (1) Calculated as the compensation provided by the Government to the affected population<br>(2) Based on the difference between the |

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|---|---|---|---|---|---|---|---|
| | | | | | | | market value of lost assets in 2013 and 1999 |
| 15 | Kar et al. | 2007 | Rs. 39.68 billion INR | | | | Source: Government of Orissa (unspecified reference) |
| 18 | Kalsi | 2006 | 2.5 billion USD | | | | Source: EM-DAT |
| 19 | Badola and Hussain | 2005 | | | | 3 villages in the Kendrapara District: 44.07 USD/household in Singdi with no mangroves/embankment; 32.31 USD/household in Bankual in the shadow of mangroves; and 153.74 USD/household loss in Bandhamal protected by an embankment. | |
| 23 | Kar et al. | 2004 | Rs. 39.68 billion INR | | | | Source: Government of Orissa (unspecified reference) |

*Infrastructural damages*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 2 | Irshad | 2017 | 1,650,086 houses damaged or | | | | Source: Evaluation study of Rehabilitation and Reconstruction Process in |

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|---|---|---|---|---|---|---|---|
| | | | destroyed; 23,129 houses washed away; 746,337 houses fully destroyed; 880,620 houses damaged; 3,425 high schools damaged; 66 colleges damaged; 14,901 primary schools damaged. 17,032 villages with affected power supply. | | | | Post-Super Cyclone, Odisha |
| 5 | Patra and Jena | 2013 | 275,000 houses | | Erasama Block of Jagatsinghpur District | | 1,670,000 homeless<br><br>Healthcare systems inoperative for weeks due to communication breakage |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | unreachable | | |
| 6 | Chhotray and Few | 2012 | 1,900,000 severely damaged houses; 800,000 houses washed away or collapsed. | | | Reported collapse of *kutcha* (mud) houses in the two villages surveyed by the study: Siyali in the Ersama Block in Jagatsinghpur District and Purbaparibadakharamanga and Andeisahi in Kantapada Block in Cuttack District. No quantitative data. | Source: Samal, K.C., Meher, S., Panigrahi, N., Mohanty, S., 2005. State, NGOs and Disaster Management. Rawat Publications, New Delhi. |
| 7 | Das | 2009 | 23,620 houses swept away; 746,322 fully collapsed; and 1,187,591 partially collapsed houses | Kendrapara: 2,761; 45,834; and 132,981 respectively | | | Original source: Emergency office and Tahasildar Office of Kendrapada |
| 14 | Das | 2007 | 2,000,000 damaged houses | | | | |

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|---|---|---|---|---|---|---|---|
| 18 | Kalsi | 2006 | 1,900,000 houses collapsed; 454 public buildings partially/fully collapsed; head works of 6 dams with structural distress | Jagatsinghpur and Kendrapara (worst affected): 350,000 houses collapsed; 250,000 houses partially collapsed | | | Sources: Government of Orissa, Indian Institute of Public Administration, New Delhi & Report of the Task Force on Repairs and Reconstruction of the Housing in the Areas Affected by Super Cyclone in Orissa prepared by Ministry of Urban Development, Govt. of India |
| 18 | Kalsi | 2006 | 454 public buildings partially/fully collapsed; 20,005 breaches in flood embankments; distress in head works of 6 dams. Bhubaneswar airport closed | | | | Sources: Government of Orissa, Indian Institute of Public Administration, New Delhi & Report of the Task Force on Repairs and Reconstruction of the Housing in the Areas Affected by Super Cyclone in Orissa prepared by Ministry of Urban Development, Govt. of India. |

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| | | | until 02/11/1999; India Meteorological Department's Cyclone Detection Radar in Paradeep damaged; Southern Railway disruption; no communication links for 24 hours; power line disruption; 20,005 breaches in flood embankment. | | | | |
| 19 | Badola and Hussain | 2005 | | | | 3 villages in the Kendrapara District: 49.47% of damage to houses per household in | |

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|---|---|---|---|---|---|---|---|
| | | | | | | Singdi with no mangroves/embankment; 28.11% in Bankual in the shadow of mangroves; and 54.95% loss in Bandhamal protected by an embankment. | |
| 21 | Thomalla and Schmuck | 2004 | Breakdown of Government infrastructure and communication systems for up to 2 weeks | | | | Source: (Disasters Emergency Committee, 2000) |
| 24 | Panigrahi | 2003 | Damages to 14,901 primary schools; 3,425 high schools; 66 colleges; 2,005 instances of flood embankm | | | In Cuttack and Bhubaneswar, essential services not restored before one week or more | Source: White Paper on Super Cyclone in Orissa. Revenue Department, Government of Orissa, December 1999.<br><br>Source: Swain, M and Panigrahi, N. 2001. Impact of Super Cyclone on the Life and Livelihood of |

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|---|---|---|---|---|---|---|---|---|
| | | | ent breaches; 8, 647 canal embankment breaches; 31 minor irrigation dam partially breached; 7,500 km district roads; 444 km rural roads; 6,391 water wells. 17,032 power supply affected villages.<br><br>Electricity, water supply and communication system not restored before six | | | | rhe Women: A Study in two Coastal Districts ofOrissa, Internal Project. NKC Center for Development Studies, Bhubaneswar. |

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|---|---|---|---|---|---|---|---|
| | | | months or more in rural areas. No access to cooked food and safe water for one week after the cyclone. | | | | |
| 28 | Das | 2001 | 1,448,638 damaged houses | Damages to houses. Puri: 10,804; Cuttack: 433,000; Kendrapara: 250,000; Nayagarh: 11,190; Khurda: 95,540; Bhadrak: 65,802; Keonjhar: 55,200; Dhenkanal: 61,429; Jagatsinghpur: 250,000; | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Jaipur: 114,633; Balasore: 92,040; Mayurbhanj: 9,000.<br><br>Groundwater pollution. | | | |
| 29 | Kundu et al. | 2001 | Road damage and failure in the communication network | | | | Source: UN, 1999, India Cyclone, 10 November 1999, http://www.un.org.in/orissa.htm (not accessible any longer) |
| 32 | Government of Orissa | 1999 | 1,579,582 houses damaged | Damages to houses. Balasore: 91,690; Bhadrak: 104,398; Cuttack: 332,255; Dhenkanal: 61,811; Jagatsinghpur: 230,508; Jaipur: 114,633; | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Kendrapara: 345,040; Keonjhar: 45,611; Khurda: 95,540; Mayurbhanj: 9,000; Nayagarh: 14,255; Puri: 134,841.<br><br>In Kendrapara, damages to 39 electric towers; national highway n. 5 from Bhubaneswar to Calcutta; 3,425 high schools and 14,901 primary | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | schools; 826 government buildings; 1,500 km of rural roadsides; 5 hospitals. | | | |

*Agricultural losses*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 2 | Irshad | 2017 | 1,300,000 paddy crop damaged; 176,000 vegetable land damaged; 257,000 other crop land damaged. | | | | Source: Evaluation study of Rehabilitation and Reconstruction Process in Post-Super Cyclone, Odisha |
| 5 | Patra and Jena | 2013 | 17,110 $km^2$ | | | | |
| 6 | Chhotray and Few | 2012 | | | | In Purbaparibadakharamanga (PP) and Andeisahi (AS) in Kantapada Block in Cuttack District: 'Given their riverside | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | location, the inland communities of PP and AS have experienced a generally worsening resource situation and recurrent flooding for years, even before the super-cyclone. For the large majority, agricultural efforts were restricted to summer cultivation of small amounts of lentils and paddy in the dry river bed and some vegetables in their small homestead lands, since most cultivable landholdings have been eroded. Each successive flood dumped sand on homesteads, further limiting the cultivation of greens and vegetables for domestic consumption.<br><br>In Siyali in the Ersama Block in Jagatsinghpur District, immediate halt in agriculture due to salinity intrusion and general | |

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|---|---|---|---|---|---|---|---|
| | | | | | | devastation after the 1999 cyclone. Very difficult to resume agricultural production in the years after up to the same pre-cyclone levels due to continued soil salinity. Attempts at prawn cultivation (strong outsider interest) as an adaptation strategy resulted in failure due to disease and debts for locals. | |
| 8 | Das and Vincent | 2009 | | | | | Average price of agricultural land in 1999: 172,970 rupees/ha. Source: personal communication, J. Dash, Indo-Asian News Service, Bhubaneswar, Orissa, June 10, 2007. |
| 9 | Abhyankar, Patwardhan and Inamdar | 2008 | | Kendrapara: 3.6504 ha rice field test site found to have | | | Source: Radarsat SAR images of 11 October and 2/4 November 1999 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | been entirely submerged | | | (obtained from Radarsat International, Canada).<br><br>Test site coordinates: Latitude 20°21’ to 20°47’N and Longitude 86°14’ to 87°83’E |
| 13 | Abhyankar, Patwardhan and Inamdar | 2007 | | Kendrapara: 29,400 ha of rice area completely submerged on November 2, 1999 and 19,400 ha completely submerged on November 4, 1999 | | | Source: pre event (October 11, 1999) and post event (November 2, 1999 and November 4, 1999) IRS 1D LISS III images (resolution = 22m) |
| 14 | Das | 2007 | 1,800,000 ha damaged crops | | | | |
| 16 | Abhyankar, Patwardhan and Inamdar | 2006 | | Kendrapara: On 02/11/1999, 23,324.64 ha | | | Source: pre-event IRS LISS III satellite image of October 11, |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | of rice recovered after cyclone; 29,037.65 ha of rice completely submerged; 21,768.82 ha of rice partially submerged; 28,198.87 ha of rice not submerged; 25,673.26 ha of rice damaged by cyclonic wind. On 04/11/1999, 21,865.22 ha of rice recovered after cyclone (on 02/11/1999); 19,137.02 ha of rice completely submerged; 13,010.36 ha of rice partially submerged; | | | 1999 (NRSA, Hyderabad, India); post-event Radarsat-1 images of 2 and 4 November 1999 (Radarsat International, Canada) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 40,186.98 ha of rice not submerged; 33,803.65 ha of rice damaged by cyclonic wind. | | | |
| 17 | Abhyankar, Patwardhan and Inamdar | 2006 | | Kendrapara: 27,505 rice area completely submerged on 02/11/1999 and 17,518 ha on 04/11/1999. | | | Source: pre-event IRS 1D LISS III (resolution = 22m) image of Kendrapara district; post-event SAR Image. |
| 22 | De, Khole and Dandekar | 2004 | 16,170 $km^2$ of paddy; 330 $km^2$ of other crops | | | | Source: (Conford, 2000) |
| 24 | Panigrahi | 2003 | Damages to 130,000 ha paddy crops; 176,000 ha vegetable crops; 257,000 | | | | Source: White Paper on Super Cyclone in Orissa. Revenue Department, Government of Orissa, December 1999. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | other cropland. | | | | |
| 28 | Das | 2001 | 1,670,023 ha of paddy crops damaged | Damage to paddy crops in ha. Puri: 152,820; Cuttack: 196,883; Kendrapara: 162,832; Nayagarh: 76,072; Khurda: 74,307; Bhadrak: 183,183; Keonjhar: 106,740; Dhenkanal: 125,422; Jagatsinghpur: 100,505; Jaipur: 187,775; Balasore: 219,135; Mayurbhanj: 85049. | | | Source: Government of Odisha |
| 32 | Government of Orissa | 1999 | Rs. 17,33 billion | Affected agricultural land in thousand ha. Balasore: | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1.41; Bhadrak: 1.83; Cuttack: 2.09; Dhenkanal: 1.38; Jagatsinghpur: 1.20; Jaipur: 1.88; Kendrapara: 1.70; Keonjhar: 1.25; Khurda: 1.02; Mayurbhanj: 2.07; Nayagarh: 0.31; Puri: 1.72. | | | |

*Other vegetation losses*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 2 | Irshad | 2017 | 9 million trees uprooted | | | | Source: Evaluation study of Rehabilitation and Reconstruction Process in Post-Super Cyclone, Odisha |
| 5 | Patra and Jena | 2013 | 90,000,000 trees | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6 | Chhotray and Few | 2012 | | | | | Depletion of fruit trees, leading to lack of fuel wood |
| 11 | Mohanty et al. | 2008 | Decreases in areas of vegetation (3394.69 $km^2$) and dense vegetation (443.15 $km^2$) | | | | Source: IRS-1D wide field sensor (WiFS) data on normalised difference vegetation index (NDVI) in the precyclone and postcyclone periods (11 October 1999 and 14 November 1999) |
| 16 | Abhyankar, Patwardhan and Inamdar | 2006 | | Kendrapara: <u>Losses by landcover class (submerged areas)</u> On 02/11/1999, 568.2456 ha of forest; 12,080.9988 of fallow land; | | | Source: pre-event IRS LISS III satellite image of October 11, 1999 (NRSA, Hyderabad, India); post-event Radarsat-1 images of 2 and 4 November 1999 (Radarsat |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 3,150.2952 ha of other vegetation. On 04/11/1999, 395.46 of forest; 7,329.3948 of fallow land; 1,749.7584 of other vegetation. | | | International, Canada) |
| 17 | Abhyankar, Patwardhan and Inamdar | 2006 | | Kendrapara: 468.5 forest area , 11,490 fallow land area and 2,567 other vegetative land completely submerged on 02/11/1999; 299 ha of forest, 6,630 of fallow land and 989 of other vegetative area | | | Source: pre-event IRS 1D LISS III (resolution = 22m) image of Kendrapara district; post-event SAR Image. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | completely submerged on 04/11/1999. | | | |
| 19 | Badola and Hussain | 2005 | | | | 3 villages in the Kendrapara District: 21% of tree damage in Singdi with no mangroves/embankment; 3.3% in Bankual in the shadow of mangroves; and 15.5% in Bandhamal protected by an embankment. | |
| 29 | Kundu et al. | 2001 | Vegetation loss as the difference in NDVI before and after the cyclone. State-level map (pp. 1384-1385) shows affected areas. | | | | Source: IRS-P4 images of 11 October and 10 November 1999 (National Remote Sensing Agency, Hyderabad, India) |
| 30 | Nayak, Sarangi and Rajawat | 2001 | Low post-cyclone NDVI as a measure of mangrove | | | | Source: IRS-P4 images of 11 October and 14 November 1999 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | loss in the Mahanadi Delta (NDVI ranging between 0.4 and 0.6 pre-cyclone, and between 0.2 and 0.4 post-cyclone). Mahanadi Delta-level map (p. 1211) | | | | |

*Livestock losses*

| **ID** | **Authors** | **Year** | **State** | **District** | **Block** | **Village** | **Other** |
|---|---|---|---|---|---|---|---|
| 2 | Irshad | 2017 | 315,886 cattle killed; 316,372 small animals killed | | | | Source: Evaluation study of Rehabilitation and Reconstruction Process in Post-Super Cyclone, Odisha |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5 | Patra and Jena | 2013 | 406,000 | | | | 5 million farmers affected |
| 6 | Chhotray and Few | 2012 | | | | | Change in livestock breeding patterns (only small livestock following reduced harvest income due to cyclone) |
| 14 | Das | 2007 | 440,000 | | | | |
| 18 | Kalsi | 2006 | 200,000 | | | | Sources: Government of Orissa, Indian Institute of Public Administration, New Delhi & Report of the Task Force on Repairs and Reconstruction of the Housing in the Areas Affected by Super |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | Cyclone in Orissa prepared by Ministry of Urban Development, Government of India. |
| 19 | Badola and Hussain | 2005 | | | | 3 villages in the Kendrapara District: 54.05 Rs./household in Singdi with no mangroves/embankment; 127.63 Rs./household in Bankual in the shadow of mangroves; and 1,044.37 Rs./household in Bandhamal protected by an embankment. | Breaches in embankments can explain the results |
| 22 | De, Khole and Dandekar | 2004 | 370,000 | | | | Source: (Conford, 2000) |
| 24 | Panigrahi | 2003 | 315,886 cattle; 316,372 small animals; 1,883,468 poultry | | | | Source: White Paper on Super Cyclone in Orissa. Revenue Department, Government of Orissa, December 1999. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 28 | Das | 2001 | 370,297 | Puri: 52,764; Cuttack: 44,137; Kendrapara: 24,207; Nayagarh: N/A; Khurda: 53,704; Bhadrak: 9,766; Keonjhar: 7,677; Dhenkanal: 11,027; Jagatsinghpur: 110,682; Jaipur: 17,000; Balasore: 38,778; Mayurbhanj: 555. | | | |
| 32 | Government of Orissa | 1999 | Buffaloes: 13,464; bullock: 52,973; cows: 156,424; calves: 90,232; sheep: 103,127; goats: | | | | Source: Director, Veterinary Services |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | 196,212; pigs: 8,945; poultry: 1,151,245. | | | | |

*Other losses*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 2 | Irshad | 2017 | 9,085 fishing boats damaged | | | | Source: Evaluation study of Rehabilitation and Reconstruction Process in Post-Super Cyclone, Odisha |
| 24 | Panigrahi | 2003 | 9,085 fishing boats damaged; 21,143 fishing nets destroyed. | | | | Source: White Paper on Super Cyclone in Orissa. Revenue Department, Government of Orissa, December 1999. |

*Averted losses*

| ID | Authors | Year | State | District | Block | Village | Other |
|---|---|---|---|---|---|---|---|
| 7 | Das | 2009 | | Kendrapara: Rs. 592,647,800 averted house damages thanks to mangrove protection – equivalent to | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Rs. 51,168/ha of mangrove forest | | | |
| 8 | Das and Vincent | 2009 | | Kendrapara: 0.0148 lives/ha of mangroves | | | |
| 14 | Das | 2007 | | Kendrapara: 211 saved lives; Rs. 1,800,000 averted damages | | | Value per ha with intact mangrove forests of Rs. 360,000; market value of land with no mangroves of Rs. 200,000. Cost of mangrove regeneration: Rs. 4500/ha. |

## A.3 Data-driven analysis of census data: correlation analysis

| | SC1 | SC2 | SC3 | SC4 | SC5 | SC6 | SC7 | SC8 | SC9 | SC10 | SC11 | SC12 | SC13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SC1 | 1 | | | | | | | | | | | | |
| SC2 | 0.267355 | 1 | | | | | | | | | | | |
| SC3 | 0.625462 | -0.01579 | 1 | | | | | | | | | | |
| SC4 | -0.09482 | 0.234455 | -0.15018 | 1 | | | | | | | | | |
| SC5 | 0.246115 | 0.078005 | 0.04031 | 0.088536 | 1 | | | | | | | | |
| SC6 | -0.12146 | -0.0412 | 0.011283 | -0.07654 | -0.47804 | 1 | | | | | | | |
| SC7 | 0.04306 | 0.189726 | 0.021085 | 0.017201 | -0.09109 | 0.213109 | 1 | | | | | | |
| SC8 | -0.05262 | 0.010378 | -0.07227 | -0.00578 | -0.03219 | 0.013409 | 0.016089 | 1 | | | | | |
| SC9 | 0.106267 | 0.185172 | 0.105744 | 0.01098 | -0.02779 | 0.058059 | 0.124296 | -0.02989 | 1 | | | | |
| SC10 | 0.08213 | 0.112112 | 0.044559 | 0.032228 | -0.025 | -0.0347 | 0.036177 | 0.000528 | 0.067534 | 1 | | | |
| SC11 | 0.055262 | 0.161459 | 0.084764 | 0.02084 | -0.0819 | 0.152958 | 0.278406 | -0.04384 | 0.160252 | 0.02299 | 1 | | |
| SC12 | -0.08056 | 0.051434 | -0.00583 | 0.000658 | -0.20943 | 0.299792 | 0.239846 | 0.060374 | 0.107569 | 0.055773 | 0.323783 | 1 | |
| SC13 | 0.036114 | 0.198846 | -0.05616 | 0.06047 | -0.09868 | 0.242445 | 0.527124 | 0.009078 | 0.079117 | 0.071977 | 0.243323 | 0.15037 | 1 |
| EC1 | -0.0691 | -0.50946 | 0.007713 | -0.18761 | 0.050215 | -0.09417 | -0.19336 | 0.023252 | -0.21122 | -0.1153 | -0.15268 | -0.13202 | -0.17631 |
| Ex EC2 | -0.1472 | -0.04959 | -0.17026 | 0.051313 | 0.039583 | -0.07408 | -0.0804 | 0.074592 | -0.12425 | -0.06287 | -0.03414 | -0.02412 | -0.02262 |
| EC2 | 0.069676 | 0.019196 | 0.118217 | -0.00814 | 0.00108 | 0.086489 | 0.025753 | -0.01963 | 0.129731 | 0.059061 | 0.064777 | 0.061583 | 0.063507 |
| EC3 | 0.099921 | 0.057276 | 0.040232 | -0.09888 | 0.021594 | -0.01063 | 0.031112 | 0.005864 | -0.00294 | -0.03868 | -0.01977 | -0.0999 | -0.03707 |
| EC4 | 0.116188 | 0.156506 | 0.065499 | 0.034958 | -0.03161 | 0.1577 | 0.152819 | 0.031058 | 0.189569 | 0.119399 | 0.253748 | 0.112558 | 0.150197 |
| EC5 | 0.156635 | 0.231458 | 0.203194 | -0.01363 | -0.12375 | 0.111205 | 0.112333 | -0.02438 | 0.317142 | 0.171582 | 0.188253 | 0.098017 | 0.053147 |
| ExEC7 | 0.137733 | 0.222554 | 0.19102 | -0.01115 | -0.13314 | 0.119084 | 0.116977 | -0.02438 | 0.309098 | 0.191502 | 0.200945 | 0.125827 | 0.056096 |
| ENC1 | -0.08665 | -0.31298 | 0.040284 | -0.16784 | -0.0081 | 0.122047 | -0.06234 | -0.01137 | -0.00905 | 0.014966 | -0.00121 | 0.057987 | -0.04815 |
| CC1 | -0.01308 | 0.000678 | -0.00049 | 0.03353 | -0.16916 | 0.053516 | -0.04561 | -0.00408 | -0.04489 | 0.017226 | -0.00128 | 0.013434 | 0.024387 |
| INFC1 | 0.052734 | 0.071683 | 0.07751 | 0.007588 | -0.0705 | 0.150351 | 0.150894 | 0.063358 | 0.023813 | -0.00281 | 0.134986 | 0.233004 | 0.110434 |
| INFC2 | 0.078234 | 0.140845 | 0.148419 | -0.04459 | -0.13736 | 0.129855 | 0.14435 | 0.068796 | 0.450862 | 0.102638 | 0.193664 | 0.227727 | 0.113016 |
| INFC3 | 0.186263 | 0.3004 | 0.124678 | 0.043901 | -0.10814 | 0.154119 | 0.298412 | -0.05187 | 0.270147 | 0.112739 | 0.279151 | 0.202472 | 0.296129 |
| INFC4 | 0.13635 | 0.098416 | 0.089241 | 0.028714 | 0.053001 | -0.08906 | 0.320873 | -0.01818 | 0.060065 | -0.01399 | -0.07705 | -0.14528 | -0.02127 |

| | EC1 | ExEC2 | EC2 | EC3 | EC4 | EC5 | ExEC7 | ENC1 | CC1 | INFC1 | INFC2 | INFC3 | INFC4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SC1 | | | | | | | | | | | | | |
| SC2 | | | | | | | | | | | | | |
| SC3 | | | | | | | | | | | | | |
| SC4 | | | | | | | | | | | | | |
| SC5 | | | | | | | | | | | | | |
| SC6 | | | | | | | | | | | | | |
| SC7 | | | | | | | | | | | | | |
| SC8 | | | | | | | | | | | | | |
| SC9 | | | | | | | | | | | | | |
| SC10 | | | | | | | | | | | | | |
| SC11 | | | | | | | | | | | | | |
| SC12 | | | | | | | | | | | | | |
| SC13 | | | | | | | | | | | | | |
| EC1 | 1 | | | | | | | | | | | | |
| Ex EC2 | 0.744281 | 1 | | | | | | | | | | | |
| EC2 | -0.3116 | -0.4026 | 1 | | | | | | | | | | |
| EC3 | 0.239475 | 0.346641 | -0.27058 | 1 | | | | | | | | | |
| EC4 | -0.06839 | 0.076344 | 0.112526 | 0.131262 | 1 | | | | | | | | |
| EC5 | -0.24743 | -0.13325 | 0.114196 | -0.02976 | 0.335403 | 1 | | | | | | | |
| ExEC7 | -0.23896 | -0.12087 | 0.107989 | -0.02433 | 0.33269 | 0.955399 | 1 | | | | | | |
| ENC1 | 0.228933 | 0.061708 | 0.030046 | -0.02718 | -0.02794 | -0.07368 | -0.04304 | 1 | | | | | |
| CC1 | -0.01694 | -0.02267 | 0.029727 | 0.019584 | 0.05397 | 0.010649 | 0.020033 | -0.02561 | 1 | | | | |
| INFC1 | -0.02809 | 0.019555 | 0.099095 | 0.006041 | 0.16051 | 0.14819 | 0.161062 | -0.07781 | 0.06013 | 1 | | | |
| INFC2 | -0.19591 | -0.10631 | 0.168222 | -0.04607 | 0.231212 | 0.390927 | 0.393803 | 0.088718 | 0.062562 | 0.138842 | 1 | | |
| INFC3 | -0.27555 | -0.12864 | 0.126448 | -0.02377 | 0.252205 | 0.280021 | 0.285837 | -0.0915 | 0.008604 | 0.217232 | 0.299035 | 1 | |
| INFC4 | 0.024509 | 0.038438 | -0.10763 | 0.238039 | 0.020363 | 0.001115 | -0.00525 | -0.02932 | -0.03337 | -0.01883 | 0.027872 | 0.034998 | 1 |

## A.4 List of interviewed key informants

| Interviewee | Organisation | Contact details | Interview data |
|---|---|---|---|
| Dr Sarat C. Sahu | India Meteorological Department (IMD) Bhubaneswar | scsahuimd@gmail.com | 08/09/15 |
| Prof. Satya Ranjan Das | Odisha University of Agriculture and Technology (OUAT) | srdas2002@gmail.com | 09/09/15 |
| Mr Kailash Chandra Dash | Regional Centre for Development Cooperation (RCDC) | kailash@rcdcindia.org | 09/09/15 |
| Mr Sudarshan Chhotray | Focus Odisha | focusodisha@gmail.com | 09/09/15 |
| Ms Binapani Mishra | Society for Women Action Development (SWAD) | swadbina@yahoo.com | 09/09/15 |
| Mr Bholonath Mishra | Odisha State Disaster Management Authority (OSDMA) | bnmishra.osdma@gmail.com | 16/09/15 |
| Dr Supriya Pattanayak | Centurion University (ex DFID Odisha) | supriya.pattanayak@gmail.com | 16/09/15 |
| Dr Smita Mishra Panda | Centurion University | smita.mishra@cutm.ac.in | 16/09/15 |
| Mr Akshaya Kumar Biswal | Oxfam India | akshaya@oxfamindia.org | 17/09/15 |
| Mr Debabrat Patra | Action Aid India | debabrat.patra@actionaid.org | 17/09/15 |
| Mr B. C. Swain | Block Office | - | 24/09/15 |

## A.5 Ethics forms, Participant Information Sheets and Consent Forms

**SSEGM ETHICS SUB-COMMITTEE APPLICATION FORM**

***Please note:***

- ***You must not begin data collection for your study until ethical approval has been obtained.***
- ***It is your responsibility to follow the University of Southampton's Ethics Policy and any relevant academic or professional guidelines in the conduct of your study. This includes providing appropriate information sheets and consent forms, and ensuring confidentiality in the storage and use of data.***
- ***It is also your responsibility to provide full and accurate information in completing this form.***

**1. Name(s):** Margherita Fanchiotti

**2. Current Position** Postgraduate Researcher, University of Southampton

**3. Contact Details:**

**Division/School** Geography & Environment

**Email** m.fanchiotti@soton.ac.uk

**Phone** 07478326560

**4. Is your study being conducted as part of an education qualification?**

**Yes** ☒ **No** ☐

**5. If Yes, please give the name of your supervisor**

Dr Jadu Dash

**6. Title of your project:**

Modelling community resilience to tropical cyclones in the Mahanadi delta, India

**7. Briefly describe the rationale, study aims and the relevant research questions of your study**

Disasters of natural origin cause many fatalities and significant economic damages every year. Among all categories of natural hazards, tropical cyclones are those associated with the highest mortality risk, and exposure to these hazards is growing worldwide as urbanisation driven by greater economic productivity is leading to higher concentrations of population in areas at risk and global warming is posing serious threats to communities. In light of this, the concept of disaster resilience has gained momentum in recent decades; however, more research is needed to develop effective computational tools for its quantification, especially in developing countries. This research is therefore aimed at investigating community resilience to tropical cyclones using the Mahanadi delta, in the coastal state of Odisha, India as a case study, with the ultimate scope of providing a modelling tool for the assessment of resilience over space and time.

**Research Aim**:

To evaluate community resilience to tropical cyclones in the Mahanadi delta, under different spatial and temporal scenarios, in relation to existing and proposed coastal infrastructure.

**Research objectives**:

1. To define a framework to assess community resilience to tropical cyclones in the study site.

2. To identify agents of resilience to tropical cyclones in the case study area based on literature review and stakeholders engagement through a bottom-up approach.

3. To develop an agent-based model to quantify the interactions between the physical and socio-economic drivers of resilience.

4. To evaluate present and future resilience under different land-use and socio-economic scenarios, under deep uncertainty of future climatic risks.

**8. Describe the design of your study**

This study builds on available literature to provide a conceptual framework for the quantification of resilience to tropical cyclones in the study site through the identification of key drivers of resilience and their indicators. A bottom-up approach with direct involvement of stakeholders in the selection and weighing of the indicators will be used. An agent-based model will then be developed to capture the interactions between agents of resilience and to allow for exploratory modelling of different land-use and socio-economic scenarios. The model is meant to aid decision making by providing computational decision support and to facilitate knowledge transferability among stakeholders. Frameworks for decision making under deep uncertainty of future climatic risks will be adopted to evaluate resilience of alternative solutions, and recommendations for policy makers will be derived based on the research findings.

An outline of the major steps involved in the study process is provided below:

i. Literature review / Background overview
ii. Resilience framework
    a. Identification of key drivers of resilience to tropical cyclones
    b. Delineation of potential indicators of resilience
    c. Refined selection of indicators based on data availability
iii. Agent-based modelling
    a. Calibration
    b. Validation
iv. Tropical cyclone resilience evaluation
    a. Present resilience
    b. Future resilience under multiple plausible scenarios
v. Discussion & Recommendations
vi. Conclusions

The scoping fieldwork for which I am requesting ethical approval will be conducted in order to involve local stakeholders in the process of selecting and weighting indicators of resilience, to ensure that a bottom-up approach is used. Research methods that will be used for this purpose include:

1. Semi-structured interviews to relevant institutional stakeholders;
2. Group activities with local residents in target villages (up to a maximum of 3 villages): Participatory Rural Appraisal (PRAs) techniques, i.e. a series of participatory approaches and methods that emphasize local knowledge and enable local people to make their own assessments and plans, will be adopted to understand the dynamics that drive disaster resilience at the community level and the interactions between different drivers of resilience as perceived by local residents. For the purpose of this research, focus group discussions will be conducted and activities such as resource and risk mapping, timeline drawing, seasonality charts and ranking exercises may be performed.
    - Additionally, individual semi-structured interviews may be used to target single participants identified during fieldtrips in the villages.

All information collected with any of these methods will be recorded.

**9. Who are the research participants?**

Research participants will belong to two categories:

1. Relevant stakeholders at the country, state and village level in India. They include representatives of disaster management authorities, local departments of agriculture, local universities, etc.

2. Adult residents (>18 years) of target villages (i.e. villages highly exposed to the risk of tropical cyclones in coastal Odisha) who will accept to take part in the research.

**10. If you are going to analyse secondary data, from where are you obtaining it?**

National census and available literature.

**11. If you are collecting primary data, how will you identify and approach the participants to recruit them to your study?**

*Please upload a copy of the information sheet if you are using one – or if you are not using one please explain why.*

Two types of approaches will be used:

- Relevant organisations have been identified based on their work in the field of disaster risk management or related fields and representatives of the organisations are being identified based on their level of expertise and work experience in the field, which may provide useful inputs for the research. They will be approached building on their collaboration with the University of Southampton as part of the two projects this research is affiliated to (DECCMA and PREFUS) and based on the researcher's previous research experience in India (prior to joining the University of Southampton) and on her collaboration with UNESCO.
- Villagers in the targeted area will be asked to participate in PRAs through collaborations with local NGOs and Jadavpur University.

**12. Will participants be taking part in your study without their knowledge and consent at the time (e.g. covert observation of people)? If yes, please explain why this is necessary.**

No.

**13. If you answered 'no' to question 13, how will you obtain the consent of participants?**

*Please upload a copy of the consent form if you are using one – or if you are not using one please explain why.*

All participants will be formally asked whether they intend to participate in the study or not through a written consent form. Two different consent forms have been prepared, one for institutional stakeholders and one for local residents, to reflect different requirements. You will find both forms attached. While it is expected that institutional stakeholders will be interviewed in English and will be able to give full informed written consent through the use of the attached consent form, the consent form for local residents will be translated in the local language by the interpreter that will facilitate focus group discussions and, given the rural context and the low literacy rates, options for providing oral consent will be also available: in the latter case, the consent form will be read out loud and translated by the interpreter; oral consent will then be recorded.

**14. Is there any reason to believe participants may not be able to give full informed consent? If yes, what steps do you propose to take to safeguard their interests?**

No.

**15. If participants are under the responsibility or care of others (such as parents/carers, teachers or medical staff) what plans do you have to obtain permission to approach the participants to take part in the study?**

This is not the case.

**16. Describe what participation in your study will involve for study participants. Please attach copies of any questionnaires and/or interview schedules and/or observation topic list to be used**

The study will make use of semi-structured interviews as the primary research instruments to involve local stakeholders working in relevant organisations and focus group discussions for local inhabitants, as well as other PRA techniques as described above (question 8). Topics that will be explored include:

- Strengths and weaknesses of structural protection measures (e.g. tropical cyclone shelters, embankments, etc.) in place in the case study area;
- Institutional strengths and gaps in managing disasters;
- Communication and information during emergencies;
- Socio-economic and environmental impacts of tropical cyclones on the community;
- Community dynamics in times of crisis;
- Recovery,
- Etc.

Questions will be targeted to recipients and modulated based on their replies. They will thus greatly differ among different stakeholders based on their role and position. Spontaneous contributions will also be taken into account.

**17. How will you make it clear to participants that they may withdraw consent to participate at any point during the research without penalty?**

This will be stated in the consent form and in participant information sheet. It will also be repeated orally at the beginning and at the end of each interview/focus group discussion and this will be translated as needed.

**18. Detail any possible distress, discomfort, inconvenience or other adverse effects the participants may experience, including after the study, and you will deal with this.**

No potential adverse effect of taking part in the interviews is being foreseen. The focus group discussions with local residents may touch topics that some of the villagers may not feel comfortable in talking about, given that it deals with personal experiences relating to coping with disasters of natural origin during which the interviewees may have experienced personal losses and great distress. However, it will be the researcher's responsibility to monitor the villagers' reactions and to do her best to make them feel at ease and to change the focus of the discussion in case of discomfort of any of the villagers.

**19. How will you maintain participant anonymity and confidentiality in collecting, analysing and writing up your data?**

All data recorded will be stored on a password-protected computer accessed by the researcher only and confidentiality will be ensured.

Relevant stakeholders working in the field of disaster management will be asked to take part in the study based on their role in their related institutions and their participation therefore will not be anonymised.

On the contrary, results of focus group discussions and other exercises with local inhabitants will be collected anonymously. Either pseudonyms or an alphanumeric system will be used in all transcripts to ensure anonymity in the treatment of collected information. For the nature itself of focus group discussions, it must be noted, however, that full anonymity within community cannot be guarantee in the collection phase since participants will be engaged in group talks and will therefore share their opinions with other community members. This however will be clearly stated ahead of the activities and will become evident during the activities, therefore participants will be fully aware of this and able to choose whether to participate in the study or not based on this too.

**20. How will you store your data securely during and after the study?**

*The University of Southampton has a Research Data Management Policy, including for data retention. The Policy can be consulted at* *http://www.calendar.soton.ac.uk/sectionIV/research-data-management.html*

All information collected will be stored on a password-protected laptop which can be accessed by the researcher only.

**21. Describe any plans you have for feeding back the findings of the study to participants.**

In the consent form for institutional stakeholders, participants will be asked to provide an email address to which research findings can be sent. This will be optional.

In the case of local residents, due to the location in relatively remote villages, limited connectivity, lower literacy levels and limited knowledge of English, findings of the study may be provided to community leaders who may then brief all participants.

**22. What are the main ethical issues raised by your research and how do you intend to manage these?**

Participants will be asked to express their opinion on some of the topics touched by the research. Participation, however, is on a voluntary basis and targeted stakeholders who will not wish to take part in the study will not be considered. The researcher will adopt a very cautious approach when asking questions and will redirect the conversation based on the participants' reactions, therefore avoiding topics that may cause discomfort or distress.

**23. Please outline any other information you feel may be relevant to this submission.**

I have already conducted fieldwork in India prior to joining the University of Southampton. More specifically, I have conducted Participatory Rural Appraisals (PRAs) in remote mountainous villages in the north of the country in the context of my MSc thesis research, with the aim of assessing disaster risk at the community level by directly engaging local residents. Prior to that, I also spent some months working as a consultant on sustainable development of informal settlements in the city of Bangalore, India. I therefore already have fieldwork experience in the same country context and I have already worked in challenging conditions. Several of the institutional stakeholders I will be interviewing are in fact people who already contributed to my MSc research (for which I was based at UNESCO).

**SSEGM ETHICS SUB-COMMITTEE APPLICATION FORM**

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- ***It is also your responsibility to provide <u>full and accurate information</u> in completing this form.***

**1. Name(s):** Margherita Fanchiotti

**2. Current Position** Postgraduate Researcher, University of Southampton

**3. Contact Details:**

**Division/School** Geography & Environment

**Email** m.fanchiotti@soton.ac.uk

**Phone** 07478326560

**4. Is your study being conducted as part of an education qualification?**

**Yes** ☒ **No** ☐

**5. If Yes, please give the name of your supervisor**

Dr Jadu Dash

**6. Title of your project:**

Community resilience to tropical cyclones: Case studies in the Mahanadi Delta, India

**7. Briefly describe the rationale, study aims and the relevant research questions of your study**

Disasters of natural origin cause many fatalities and significant economic damages every year. Among all categories of natural hazards, tropical cyclones are those associated with the highest mortality risk, and exposure to these hazards is growing worldwide as urbanisation driven by greater economic productivity is leading to higher concentrations of population in areas at risk and global warming is posing serious threats to communities. In light of this, the concept of disaster resilience has gained momentum in recent decades; however, more research is needed to gather evidence of what resilience is and what it means in practice, especially in developing countries. This research is therefore aimed at investigating community resilience to tropical cyclones using the Mahanadi delta, in the coastal state of Odisha, India as a case study, with the ultimate scope of building case studies of resilience in the study place.

**Research Aim**:

To investigate if community development indicators at a strategic scale coincide with community perceptions of development and to establish the nexus between development and resilience to natural hazards as perceived by local communities.

**Research objectives**:

I) Identify past development gains and losses and their drivers in the study site using strategic development indicators

II) Establish if community perceptions of development coincide with strategic, data-driven development indicators

III) Establish the nexus between development indicators and community perceptions of resilience to natural hazards

IV) Consider policy implications of this work.

**8. Describe the design of your study**

The purpose of this study is to contribute to understanding of the nature of disaster resilience by investigating its empirically derived determinants and specific characteristics as perceived by local communities in the study site, in an effort to shed light on the practical characteristics of community resilience for people in areas at risk. To do so, a data-driven approach will be used to identify spatial and temporal development changes across communities in the study site and their drivers. Stakeholders verification of these data-derived indicators of development through extensive fieldwork in selected communities will be used to investigate how development gains and losses have been perceived to impact resilience at the community level. The relation between development and resilience is, thus, informed by local communities.

The main research steps include:

0. Literature review and background overview

- Database of disaster resilience drivers and indicators based on existing frameworks for disaster resilience assessment
- Scoping fieldwork to explore dynamics of community resilience to natural hazards in the study site

1. Data-driven, quantitative analysis of development gains and losses
    - Identification of change from data
    - Data-informed characterisation of key development drivers
    - Identification of development hotspots
2. Qualitative analysis of community perceptions of development changes, their drivers and their relation with community resilience to natural hazards in selected development hotspots
    - Community perception of development and verification of data-driven, strategic evidence of change
    - Community perception of the impact of development on community resilience
3. Data-informed, community-based disaster resilience assessment
    - Integration of quantitative and qualitative evidence
    - Validation through an independent parameter (i.e., crop production estimated from remote sensing)
    - Policy recommendations

The scoping fieldwork for which I am requesting ethical approval will be conducted in order to involve local stakeholders in the process of selecting and weighting indicators of resilience, to ensure that a bottom-up approach is used. Research methods that will be used for this purpose include:

3. Semi-structured interviews to relevant institutional stakeholders;
4. Group activities with local residents in target villages (up to a maximum of 3 villages): Participatory Rural Appraisal (PRAs) techniques, i.e. a series of participatory approaches and methods that emphasize local knowledge and enable local people to make their own assessments and plans, will be adopted to understand the dynamics that drive disaster resilience at the community level and the interactions between different drivers of resilience as perceived by local residents. For the purpose of this research, focus group discussions will be conducted and activities such as resource and risk mapping, timeline drawing, seasonality charts and ranking exercises may be performed.
    - Additionally, individual semi-structured interviews may be used to target single participants identified during fieldtrips in the villages.

All information collected with any of these methods will be recorded.

## 9. Who are the research participants?

Research participants will belong to two categories:

3. Relevant stakeholders at the country, state and village level in India. They include representatives of disaster management authorities, local departments of agriculture, local universities, etc.
4. Adult residents (>18 years) of target villages (i.e. villages highly exposed to the risk of tropical cyclones in coastal Odisha) who will accept to take part in the research.

**10. If you are going to analyse secondary data, from where are you obtaining it?**

National census and available literature.

**11. If you are collecting primary data, how will you identify and approach the participants to recruit them to your study?**

*Please upload a copy of the information sheet if you are using one – or if you are not using one please explain why.*

This fieldwork will build on connections established during a preliminary scoping fieldwork that I conducted in August-September 2015 as part of the same research study (ERGO Submission Number 16126). More specifically, two types of approaches will be used:

- Relevant organisations have been identified based on their work in the field of disaster risk management or related fields and representatives of the organisations are being identified based on their level of expertise and work experience in the field, which may provide useful inputs for the research. They will be approached building on their collaboration with the University of Southampton as part of the two projects this research is affiliated to (DECCMA and PREFUS) and based on the researcher's previous research experience in India (prior to joining the University of Southampton) and on her collaboration with UNESCO.
- Villagers in the targeted area will be asked to participate in PRAs through collaborations with local NGOs and Jadavpur University.

**12. Will participants be taking part in your study without their knowledge and consent at the time (e.g. covert observation of people)? If yes, please explain why this is necessary.**

No.

**13. If you answered 'no' to question 13, how will you obtain the consent of participants?**

*Please upload a copy of the consent form if you are using one – or if you are not using one please explain why.*

All participants will be formally asked whether they intend to participate in the study or not through a written consent form. Two different consent forms have been prepared, one for institutional stakeholders and one for local residents, to reflect different requirements. You will find both forms attached. While it is expected that institutional stakeholders will be interviewed in English and will be able to give full informed written consent through the use of the attached consent form, the consent form for local residents will be translated in the local language by the interpreter that will facilitate focus group discussions and, given the rural context and the low literacy rates, options for providing oral consent will be also available: in the latter case, the consent form will be read out loud and translated by the interpreter; oral consent will then be recorded.

**14. Is there any reason to believe participants may not be able to give full informed consent? If yes, what steps do you propose to take to safeguard their interests?**

No.

**15. If participants are under the responsibility or care of others (such as parents/carers, teachers or medical staff) what plans do you have to obtain permission to approach the participants to take part in the study?**

This is not the case.

**16. Describe what participation in your study will involve for study participants. Please attach copies of any questionnaires and/or interview schedules and/or observation topic list to be used**

The study will make use of semi-structured interviews as the primary research instruments to involve local stakeholders working in relevant organisations and focus group discussions for local inhabitants, as well as other PRA techniques as described above (question 8). Topics that will be explored include:

- Strengths and weaknesses of structural protection measures (e.g. tropical cyclone shelters, embankments, etc.) in place in the case study area;
- Institutional strengths and gaps in managing disasters;
- Communication and information during emergencies;
- Socio-economic and environmental impacts of tropical cyclones on the community;

- Community dynamics in times of crisis;
- Recovery,
- Etc.

Questions will be targeted to recipients and modulated based on their replies. They will thus greatly differ among different stakeholders based on their role and position. Spontaneous contributions will also be taken into account.

**17. How will you make it clear to participants that they may withdraw consent to participate at any point during the research without penalty?**

This will be stated in the consent form and in participant information sheet. It will also be repeated orally at the beginning and at the end of each interview/focus group discussion and this will be translated as needed.

**18. Detail any possible distress, discomfort, inconvenience or other adverse effects the participants may experience, including after the study, and you will deal with this.**

No potential adverse effect of taking part in the interviews is being foreseen. The focus group discussions with local residents may touch topics that some of the villagers may not feel comfortable in talking about, given that it deals with personal experiences relating to coping with disasters of natural origin during which the interviewees may have experienced personal losses and great distress. However, it will be the researcher's responsibility to monitor the villagers' reactions and to do her best to make them feel at ease and to change the focus of the discussion in case of discomfort of any of the villagers.

**19. How will you maintain participant anonymity and confidentiality in collecting, analysing and writing up your data?**

All data recorded will be stored on a password-protected computer accessed by the researcher only and confidentiality will be ensured.

Relevant stakeholders working in the field of disaster management will be asked to take part in the study based on their role in their related institutions and their participation therefore will not be anonymised.

On the contrary, results of focus group discussions and other exercises with local inhabitants will be collected anonymously. Either pseudonyms or an alphanumeric system will be used in all transcripts to ensure anonymity in the treatment of collected information. For the nature itself of focus group discussions, it must be noted, however, that full anonymity within community cannot be guarantee in the collection phase since participants will be engaged in group talks and will therefore share their opinions with other community members. This however will be clearly stated ahead of the activities and will become evident during the activities, therefore participants will be fully aware of this and able to choose whether to participate in the study or not based on this too.

**20. How will you store your data securely during and after the study?**

*The University of Southampton has a Research Data Management Policy, including for data retention. The Policy can be consulted at [http://www.calendar.soton.ac.uk/sectionIV/research-data-management.html](http://www.calendar.soton.ac.uk/sectionIV/research-data-management.html)*

All information collected will be stored on a password-protected laptop which can be accessed by the researcher only.

**21. Describe any plans you have for feeding back the findings of the study to participants.**

In the consent form for institutional stakeholders, participants will be asked to provide an email address to which research findings can be sent. This will be optional.

In the case of local residents, due to the location in relatively remote villages, limited connectivity, lower literacy levels and limited knowledge of English, findings of the study may be provided to community leaders who may then brief all participants.

**22. What are the main ethical issues raised by your research and how do you intend to manage these?**

Participants will be asked to express their opinion on some of the topics touched by the research. Participation, however, is on a voluntary basis and targeted stakeholders who will not wish to take part in the study will not be considered. The researcher will adopt a very cautious approach when asking questions and will redirect the conversation based on the participants' reactions, therefore avoiding topics that may cause discomfort or distress.

**23. Please outline any other information you feel may be relevant to this submission.**

This fieldwork will build on connections established during a preliminary scoping fieldwork that I conducted in August-September 2015 as part of the same research study (**ERGO Submission Number 16126**). Several of the institutional stakeholders I will be interviewing are people whom I have already interviewed during the scoping fieldwork.

Furthermore, I have already conducted fieldwork in India prior to joining the University of Southampton. More specifically, I have conducted Participatory Rural Appraisals (PRAs) in remote mountainous villages in the north of the country in the context of my MSc thesis research, with the aim of assessing disaster risk at the community level by directly engaging local residents. Prior to that, I also spent some months working as a consultant on sustainable development of informal settlements in the city of Bangalore, India. I therefore already have fieldwork experience in the same country context and I have already worked in challenging conditions.

# Participant Information Sheet – For institutional stakeholders

**Study Title**: Community resilience to tropical cyclones: Case studies in the Mahanadi delta, India

**Researcher**: Margherita Fanchiotti **Ethics number**: 16126

**Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.**

### What is the research about?

This research investigates community resilience to tropical cyclones in the Mahanadi delta, Odisha, and is part of my PhD work. The aim of the project is to develop a modelling tool to assess disaster resilience over space and time, looking at variations across different land-use and socio-economic scenarios to understand the role and impact of different social, economic, infrastructural, institutional and environmental agents of resilience at the community level. The study is part of 'DEltas, vulnerability and Climate Change: Migration and Adaptation' (DECCMA), a project jointly funded by UK Aid and Canada Aid.

### Why have I been chosen?

You have been selected to take part in the study, should you agree to do so, in full appreciation of your extensive work experience and high level of expertise in the field, which could be highly beneficial for the study.

### What will happen to me if I take part?

Should you accept to take part in the study, you will agree on being interviewed by the researcher on issues relating to disaster resilience in the case study area. The interview will last approximately one hour and it may be arranged at your best convenience in a location of your choice. All questions will be scientifically-oriented and relevant to your field of expertise and/or work experience.

### Are there any benefits in my taking part?

Your contribution will provide added value to the study and will improve current knowledge of the dynamics driving disaster resilience in Odisha. Results of the study may help informing policy making and may be beneficial for your professional life. You will be acknowledged for your contribution in all working papers, peer-reviewed publications and any other research outcome that will result from the study.

### Are there any risks involved?

No risks are being foreseen. In case you agree on participating in the study, you may still refuse to reply to any question that you do not find appropriate or relevant.

### Will my participation be confidential?

All information disclosed during the interview will be treated in compliance with the Data Protection Act/University policy of the University of Southampton, UK and will be password-protected. The information will be accessed by the researcher only. If you accept to take part in the study, you will be requested to sign a consent form where you authorise the researcher to use the information gathered during the interview for research purposes, provided that you will be acknowledged as an informant in every resulting document that may build on the information you disclosed.

### What happens if I change my mind?

You may withdraw at any time, in which case none of the information you may have previously provided will be used and all recorded information will be destroyed.

### What happens if something goes wrong?

In the unlikely case of concern or complaint, you may contact the Head of Research Governance at the University of Southampton (Tel.:+4402380595058; Email rgoinfo@soton.ac.uk), which is independent from this research.

### Where can I get more information?

For further information, you may visit the DECCMA project website: www.deccma.com.

Please feel free to contact me at any time:

Margherita Fanchiotti

Postgraduate Researcher

Geography & Environment

University of Southampton

Email: M.Fanchiotti@soton.ac.uk

Should you wish to speak with my supervisor, please contact:

Dr Jadu Dash

Associate Professor

Geography & Environment

University of Southampton

Email: J.Dash@soton.ac.uk

# Participant Information Sheet – For residents

**Study Title**: Community resilience to tropical cyclones: Case studies in the Mahanadi delta, India

**Researcher**: Margherita Fanchiotti **Ethics number**: 16126

**Please read this information carefully before deciding to take part in this research. If you are happy to participate you will be asked to sign a consent form.**

### What is the research about?

This study investigates the factors that may enable a community to better cope with future tropical cyclones. This is includes a number of factors that can be social, economic, institutional, infrastructural or environmental. The research is part of a large project funded by the UK and Canada to study disaster risk management in your area.

### Why have I been chosen?

Your village has been selected as a case study for the project. I would therefore be happy to get to know more about your personal experiences and points of view relating to coping with tropical cyclones in your village.

### What will happen to me if I take part?

In case you are willing to collaborate on the study, I would like to form groups of all people from your village who have accepted to take part in the research and to have an informal and relaxed group conversation about your previous experience in facing tropical cyclones, the institutional measures in place to reduce risk and your opinion on their effectiveness, the role of shelters and other structural protection in place in your village and your viewpoints on what could be improved and what is already working well.

### Are there any benefits in my taking part?

You will hopefully spend some entertaining hours talking with me and your fellow villagers, and your contribution will be of great help for the research as you will be given the opportunity to express your opinions and provide an insight into what actual residents think is working or should be improved in terms of disaster risk management.

### Are there any risks involved?

No risks are being foreseen for taking part in the group discussions. However, there may be topics you may not be comfortable talking about, in which case you are absolutely free not to reply and you may ask me to change the focus of the discussion. You may also choose which groups to work in and whether you prefer to work in a male/female group only or in a mixed one.

### Will my participation be confidential?

All information disclosed during the interview will be treated in compliance with the Data Protection Act/University policy of the University of Southampton, UK and will be password-protected. Your contribution will be anonymous and the information you will choose to disclose will be accessed by me only.

### What happens if I change my mind?

You are free to decide to withdraw your participation in the study at any time, in which case none of the information you may have previously provided will be used and all recorded information will be destroyed.

### What happens if something goes wrong?

In the unlikely case of concern or complaint, you may contact the Head of Research Governance at the University of Southampton (Tel.:+4402380595058; Email rgoinfo@soton.ac.uk), which is independent from this research.

### Where can I get more information?

For further information, you may visit the DECCMA project website: www.deccma.com.

Please feel free to contact me at any time:


Margherita Fanchiotti

Postgraduate Researcher

Geography & Environment

University of Southampton

Email: M.Fanchiotti@soton.ac.uk

Tel.: XXX


Should you wish to speak with my supervisor, please contact:


Dr Jadu Dash

Associate Professor

Geography & Environment

University of Southampton

Email: J.Dash@soton.ac.uk

## CONSENT FORM – For institutional stakeholders

**Study title**: Community resilience to tropical cyclones: Case studies in the Mahanadi delta, India

**Researcher name**: Margherita Fanchiotti

**Ethics reference**: 16126

*Please initial the box(es) if you agree with the statement(s):*

I have read and understood the information sheet (INSERT THE DATE AND VERSION NUMBER OF YOUR PARTICIPANT INFORMATION SHEET BETWEEN THESE BRACKETS) and have had the opportunity to ask questions about the study. ☐

I agree to take part in this research project and agree for my data to be recorded and ☐

I consent to having my responses identified personally with me in reports of the research ☐

I understand my participation is voluntary and I may withdraw at any time without my legal ☐

***Data Protection***

*I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study.*

Name of participant (print name)…………………………………………………

Signature of participant……………………………………………………………..

Date…………………………………………………………………………………

I wish to be informed about the outcomes of the research at the following email address (optional):……………………………………………………………………………………….

**CONSENT FORM – For residents**

**Study title**: Community resilience to tropical cyclones: Case studies in the Mahanadi delta, India

**Researcher name**: Margherita Fanchiotti

**Ethics reference**: 16126

*Please initial the box(es) if you agree with the statement(s):*

I have read and understood the information sheet (INSERT THE DATE AND VERSION NUMBER OF YOUR PARTICIPANT INFORMATION SHEET BETWEEN THESE BRACKETS) and have had the opportunity to ask questions about the study. ☐

I agree to take part in this research project and agree for my data to be recorded and used ☐

I understand that my responses will be anonymised in reports of the research ☐

I understand my participation is voluntary and I may withdraw at any time without my legal ☐

***Data Protection***

*I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study.*

Name of participant (print name)…………………………………………………

Signature of participant……………………………………………………………..

Date………………………………………………………………………………

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