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

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Abstract:	Climate-related hazards accounted for over 90% of disasters over the past two decades and cause massive losses every year worldwide. In the face of the climate crisis, we are confronted with unprecedented challenges that require transformational change. The Sustainable Development Goals, the Paris Agreement and the Sendai Framework for Disaster Risk Reduction set ambitious global goals and targets. Monitoring and reporting are fundamental towards their achievement. We are, thus, faced with an urgency to step up accountability efforts. India is one of the top ten countries by cumulative disaster losses, with the most intense recorded event being the 1999 Odisha super cyclone. Twenty years later, there is still no comprehensive documentation of the losses caused by the cyclone at the micro-level, nor an understanding of long-term post-disaster recovery patterns. To fill this gap, a systematic review has been conducted to gather evidence of recorded losses by type and their spatial distribution. Results show that satellite remote sensing has contributed to a finer and more localised estimation of losses compared to official records from 1999; that coastal and riverine districts are proven to be the worst impacted; and that we now have an understanding, albeit partial, of the nonphysical impacts associated with the 1999 cyclone. This review provides the most comprehensive catalogue of documented losses induced by the 1999 super cyclone and is the best estimate of a baseline of impacts which can serve to investigate long-term recovery trends.
Response to Reviewers:	

Authors' reply to reviewers' comments

Reviewer n. 1

1. No doubt, the topic of this systematic review is important for designing disaster management strategies and policies.
2. The greatest limitation of this review paper is that it does not reflect upon the true ground level 1999-cyclone induced losses occurred in the state of Odisha. The authors have not taken care of the documents such as the then news local news paper articles, fact papers/reports/sheets published by NGOs etc. This seriously impairs the implications and outcomes of this study. It seems that the paper has been written just for the sake of completing a review work without drawing any important lessons that should be kept in mind while designing disaster management strategies.
    - This has been more clearly stated among the limitations flagged in the article. While this is true, many of the studies are cited in the papers retained for the review and all those that have been mentioned by key informants have been included. The lack of digitalisation of information dating back in time, limited archiving capacities and the use of the English language only have been flagged as limitations. Nonetheless, the article still provided the most comprehensive review of losses for the specific disaster event that has ever been made. No such study existed before and its absence hampered an understanding of recovery patterns given the absence of baseline data.
3. The inclusion of only a few studies has limited the outcome of the review and could not give proper justification to the research questions.
    - See above comment on the fact that the retained articles do make reference to all existing grey literature we are aware of. Language and other limitations have been flagged.
4. This review paper could have been written focusing the comparable losses that have occurred due to Phailin (2013), HudHud (2014) and Fani (2019).
    - This would be an interesting follow-up study, which would however require the development of a methodology on how to compare those losses, given the significant improvements in forecasting, awareness, communication, response, monitoring and reporting that have occurred since 1999. 1999 was a landmark event for the development of the state disaster management system, which has significantly evolved since. Much of the difference in losses among the various cyclones is also heavily influenced by different physical hazard characteristics which understandably led to different impacts. This has been added in the discussion/conclusion sections of the article.
5. It is not sufficient to assess the losses caused by only one cyclone, rather it is desirable to identify the pattern of losses occurred in similar cyclones. This sort of systematic review can help formulating policies and strategies for effective/efficient disaster management.
    - Every cyclone is different from a physical hazard viewpoint. Furthermore, the disaster management system has evolved ever since. This makes a comparison challenging. Nevertheless, it is important to perform the same studies for other

cyclones as well and conclusions can then be drawn accordingly. This has been added in the discussion/conclusion sections of the article.

Reviewer n. 2

The manuscript has attempted to evaluate and review losses due to the 1999 super cyclone in Odisha. The authors present a narrative review methodology using 32 selected articles and evaluated losses of various parameters by asking three main research questions. The manuscript is very useful to understand various parameters to perform impact assessment of a very severe cyclone. However, the manuscript has many shortfall, which needs to be incorporated based on critical synthesis of quantitative information. The authors should add some novelties in their critical synthesis of information and presentation. It is not clear how the study fits into existing knowledge and intends to increase evaluation of loss parameters in a crisp manner. I will suggest a major revision with improvements in following points.

Comments:

1. In Abstract: It is not clear about main results. It says that "Results show that satellite remote sensing has contributed to a finer and more localised estimation of losses compared to official records from 1999; that coastal districts are proven to be the worst impacted". In fact, I don't see any critical analysis presented on usages of satellite remote sensing except a NDVI Figure to draw this conclusion. 2. In Abstract: Coastal districts are proven to be the worst impacted, however this is a known fact. In the figure related to NDVI change, the area which are far from coast (> 100 miles) are still showing moderately impacted which is not TRUE. The same moderate impact are also shown along the coast.

- All areas showing high impact from the NDVI figure that is referenced in this comment are coastal districts. When looking at moderate impact, these are all coastal and riverine districts. This has been clarified in the abstract/article.

3. Table 1.2 should be moved to the Supplement/Appendix.
    - We find this should remain here to allow the readers to easily see which papers were retained and more easily follow the presentation of results afterwards. For this reason, it has been left in the main body of the article. More detailed analysis is, however, included as a supplement/appendix.
4. L589-611 should be shortened as information was not accounted or move to Supplement/Appendix.
5. Some latest relevant paper may be updated published in 2018 and 2019.
    - The search has been re-run to refresh results. One more paper was retained (Parida, 2019).
6. Results (Question 01): Authors need to present a Table containing critical synthesis of quantitative information of all parameters used in Table 1.3 from the 20 papers.
    - Added under question 1, covering summary of all key information across research questions.

7. Results (Question 02, What is the spatial distribution of these damages?) Authors need to present a Table/Map containing important damage parameters like Agriculture, Infrastructure, diseases, mortality, economic losses, etc. related to tropical cyclones.
    - Added under question 1, covering summary of all key information across research questions.
8. Results (Question 03, Which areas have been worst affected?) Agricultural losses are given in details by Parida et al., 2019 (https://doi.org/10.1016/j.rsase.2018.03.010) and these information are still missing in the manuscript. Similarly, a paper by Sahoo and Bhaskaran, 2020 (https://doi.org/10.1016/j.jenvman.2017.10.075) also presents losses related to the physical, environmental, social, and economic impacts by the cyclones and these information are still missing in the manuscript.
    - The agricultural losses given by Parida (2019) are those from official government data (Government of Odisha, 1999), which already referenced in the paper under research question 3. The search has, however, been re-run to refresh results and make sure more recent papers are included. Parida (2019) has emerged from the search and has been added accordingly. The paper by Sahoo and Bhaskaran (2020) has not come up as a result of the search with the given search criteria and has also not been added because it does not cover the 1999 cyclone.
9. Line 917: Figure 1.2c not shown.
    - It is the NDVI figure 1.2, which has three elements (a, b, c) as referenced in the figure caption.
10. For Question 03, I will suggest to present a table showing the synthesis of quantitative information of vital parameters.
    - Added under question 1, covering summary of all key information across research questions.
11. A discussion section is missing with special emphasis on tropical cyclones and losses in response to climate change for Odisha coast.
    - Added.

Reviewer no. 3

1. Minor comments: what is idem? 'idem' has been used as citations. Kindly revise.
    - ‘Idem’ is used to repeat the preceding citation, as per citation standards.
2. Sentence 320 : literature is repeated twice.
3. Other comment: If possible, please update the abstract: adding a sentence on recommendations on how to improve practise for disaster loss data for the Government of Odisha.
    - Added.

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

1.1 Introduction

On a global scale, tropical cyclones[1] 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

[1] 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 (Anthes, 2016; Emanuel, 2003, 2005; Gray, 1968; Piddington, 1848; WMO, 2006).

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; 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 drivers 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[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).

[2] According to the India Meteorogical Department, storms are classified as “super cyclonic” if characterised by an associated wind speed of 120 knots and above (IMD (India Meteorological Department), 2008).

Total water levels combining storm surge, tides and waves have been estimated by the Odisha State Disaster Management Authority (OSDMA) (Figure 1.1).

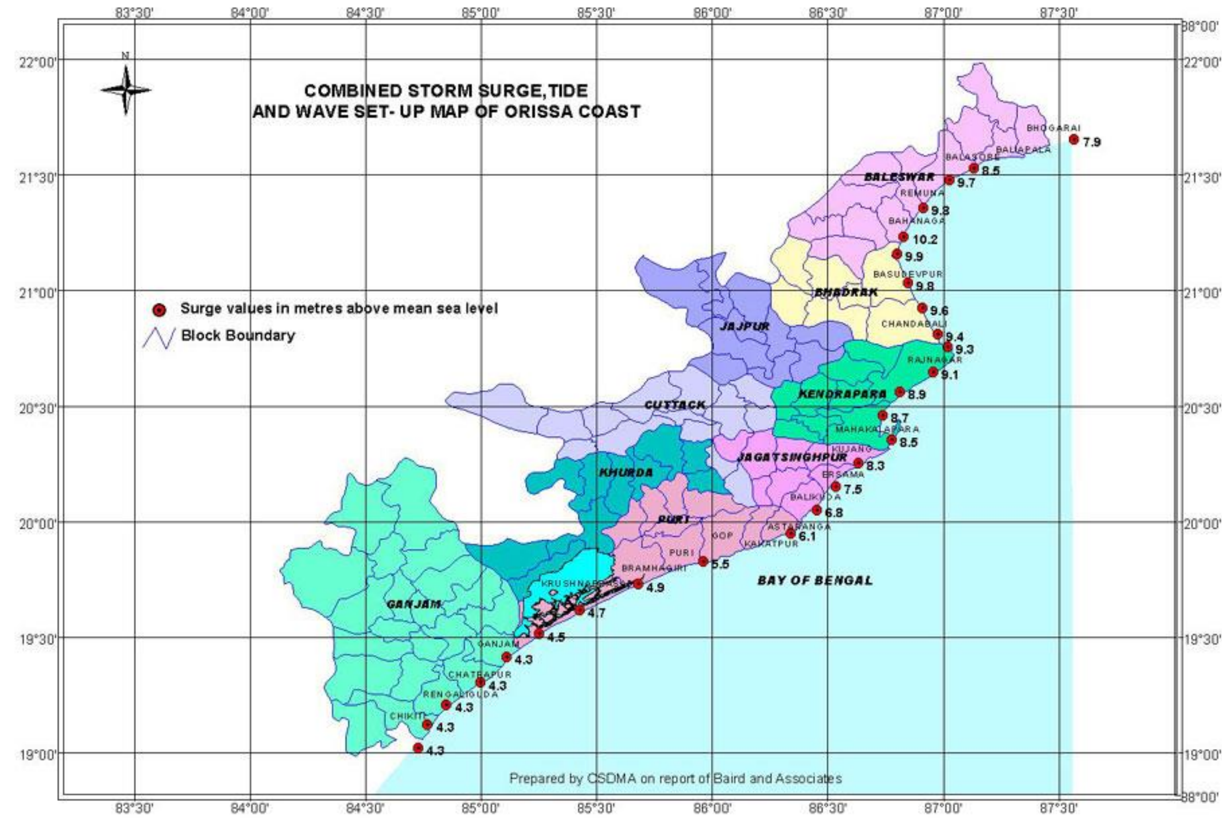

Figure 1.1: Estimated combined storm surge, tide and wave setup along the coast of Odisha (OSDMA)

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 three 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.

1.2 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 1.1. Given the large number of returned papers, only the first ten pages of results from Google Scholar were reviewed.

Keywords	**Database**	**All records**	**Journal articles**
cyclone AND 1999 AND Orissa	Web of Science	45	38
cyclone AND 1999 AND Odisha	Web of Science	12	12
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

Table 1.1: Keyword combinations and number of papers found

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.

1.3 Data and metadata

The list of retained papers, including metadata on authorship, year of publication, title and main topic, is provided in Table 1.2 below. All papers are displayed by publication year.

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 Due to Tropical Cyclone using Satellite Data: An 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	Environmental Conservation

			function of Bhitarkanika mangrove ecosystem, India	
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 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 agencies - A case study of the Super Cyclone of Orissa	Social Change
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	Epidemiology and Infection

			outbreak subsequent to the super cyclone in Orissa, India	
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*)

Table 1.2: Retained papers

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.

1.4 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, the number of articles providing information on those type of losses by scale (State, District, Block or town/village) and a summary of what these losses are is given in Table 1.3. The detailed data by loss type gathered from all reviewed papers is annexed to this article (Appendix B).

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**	

Table 1.3: Number of papers by loss type and scale, with key findings

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 1.2).

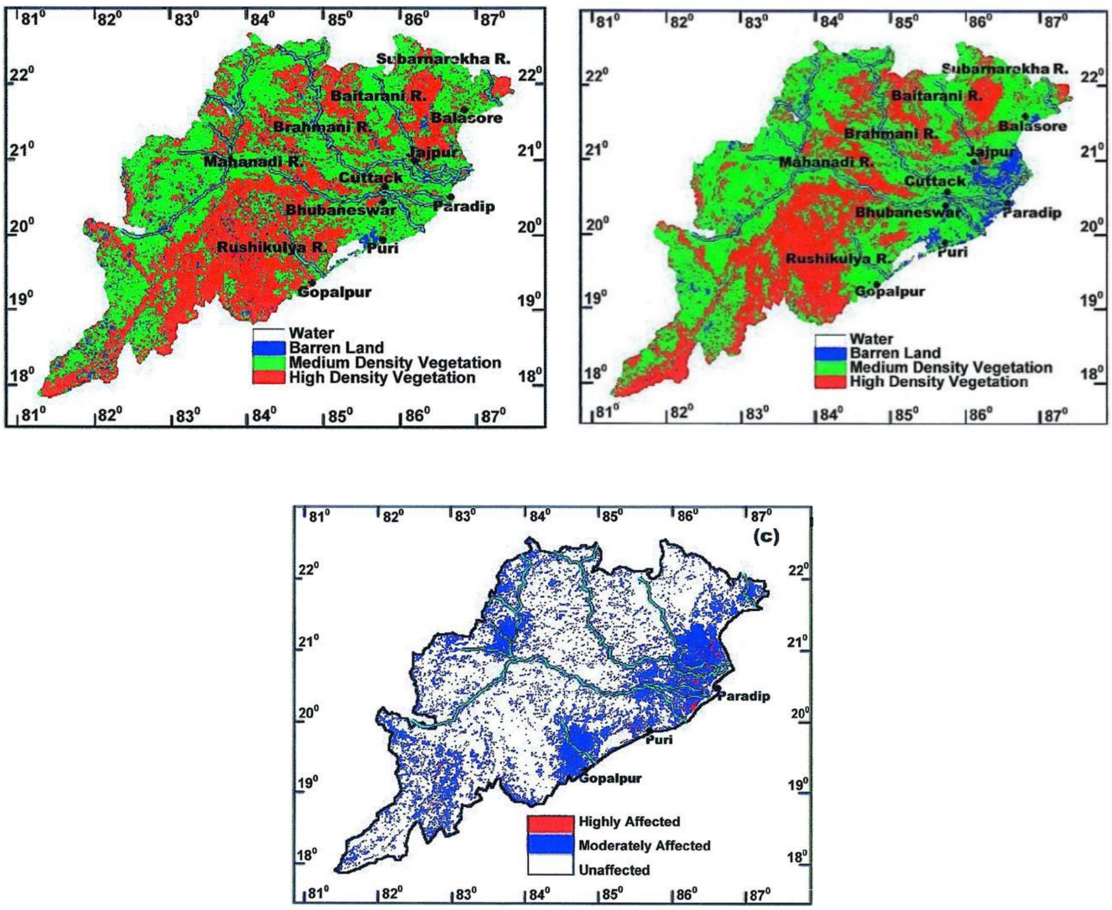

Figure 1.2: NDVI classes at State level for (a) October 1999; (b) November 1999; (c) NDVI difference between pre- and post-cyclone, showing regions affected by the cyclone (Kundu et al., 2001)

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), 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 1.2c).

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.

1.5 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 and riverine 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 and riverine 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 underinvestigated.

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.

1.6 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.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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