National Cyclone Risk Mitigation Project (NCRMP)

National Disaster Management Authority (NDMA)

Consulting Services for Hazard, Risk and Vulnerability Assessment for 13 states and UT's in India

Risk Assessment Report for Andhra Pradesh and Odisha

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Executive Summary

The present study is a part of the NCRMP project and aims to carry out Hazard, Vulnerability and Risk Assessment associated to cyclone, storm surge, and rainfall induced flooding associated with cyclones for the 13 coastal States/UTs of India by applying a deterministic approach. Specifically, the study area for this study is the coastal area of these states and UTs, which lie up to 10 m elevation (with reference to mean-sea level along the coastline). The study also aims at developing a standardized spatial database, maps, and a web-based GIS Risk Atlas to help decision makers in the States/UTs and Central Government to make informed decisions regarding mitigation measures to protect the people and assets in these coastal regions.

Cyclone Hazard assessment (Wind, Storm Surge, Flooding)

Hazard assessment was carried out for cyclonic wind, storm surge and cyclone induced flooding. For cyclonic wind and storm surge modeling, frequency and severity of historical events were used. A frequency and severity analysis of the historical cyclone catalog from 1877 to 2014 revealed that the Indian coastline can be divided into 5 severity zones varying from very high to low severity zones. Accordingly, the coasts of West Bengal and Odisha come under the very-high severity zone (Zone 1), that of Andhra Pradesh (AP) under the high severity zone (Zone 2), while the coasts of Tamil Nadu, Karnataka, Maharashtra, and Gujarat (Zone 3 and 4) come under the moderate severity zone, and Kerala comes under the low severity zone (Zone 5).

Storm-surge hazard modeling assesses the surge heights generated along the coastline and estimates the potential inundation. Flood hazard modeling assesses the flood hazard associated with rainfall generated by cyclones for the study area. Flood hazard has been assessed for major river systems across the pilot study area (Subarnarekha, Brahmani Baitarani, Mahanadi, Godavari, Krishna, and Pennar river basins) to estimate the potential inundation from cyclone induced rainfall.

These models were validated and calibrated against key historical cyclones using observed data associated to those historical events. The calibrated models were used to generate the estimates of wind speeds and surge heights associated to every historical event at model grid points over the study area. Gumbel's extreme value probability distribution was applied to modeled wind speeds and surge inundation depths to derive additional deterministic scenarios of maximum wind speeds for key return periods (2, 5, 10, 25, 50, and 100 years).

Key Findings of Cyclone Hazard Assessment

- Analysis of historical cyclonic events across all five zones indicates that the frequency of Very Severe Cyclonic Storms is higher than Severe Cyclonic Storms. This is contrary to the normal behaviour of hazards as per which the stronger events are rarer. This suggests that the potential for more frequent larger losses in India is higher.
- Comparing severity of Zone-1 and Zone-2, one observes that the total number of cyclones that have hit Zone 1 is much higher than Zone 2 indicating that the hazard is much higher in Zone 1 than in Zone 2. However, another interesting finding is that 13 severe cyclonic storms struck the Zone-2 whereas Zone-1, which comes in very-high severity zone, has been affected by only 8 severe cyclonic storms. This suggests that the potential for more frequent moderate losses is high in Zone-2 as compared to Zone-1.
- It is observed from modeling cyclone-induced rainfall that it is the translational speed of the cyclone that plays an important role in flooding. Slower moving cyclones cause more flooding irrespective of their strength.

- In Andhra Pradesh, Guntur, Krishna, and Srikakulam could experience winds of about 128-136 km/h under a 100-year return period scenario. The most vulnerable low-lying areas of Guntur and Krishna are prone to high water levels due to storm surge flooding.
- In Andhra Pradesh, cyclone induced flooding is mainly due to flooding in the small east flowing rivers, as the discharge carrying capacity of these rivers is comparatively low.
- In Andhra Pradesh, the coastal region of East Godavari district and the delta region of the Krishna and Guntur districts are highly affected due cyclone induced flooding. However, the Prakasham and Nellore districts get flooded due to Pennar and other rivers with smaller flows.
- In Odisha, the delta region of Mahanadi and Brahmani-Baitarani rivers and in Andhra Pradesh the delta region of Krishna and Godavari rivers is highly vulnerable due to cyclone-induced flood.
- In a 100-year return period scenario event, Jagatsinghpur, Kendrapara, and Ganjam districts are more vulnerable to cyclonic wind hazard with Jagatsinghpur most vulnerable to strong winds (about 144 km/h). Northern Odisha is more prone to cyclone surge with average flood depth varying between 0.5 - 5.6 m. The Puri and Ganjam districts are less prone to storm surge with average flood depths ranging around 0.5 - 4.0 m.
- Kendrapara, Bhadrak, Baleshwar, and Jajpur districts are the most affected due to cyclone induced flooding. This region gets heavily flooded even due to a marginal increase in river flows. However, Puri and Jagatsinghpur districts are less affected due to cyclone induced flooding with the exception of a few village pockets.

Exposure Data Development

Exposure is a critical component of any risk model. Exposure constitutes the population, the built environment, the infrastructure, and/or any other elements present in hazard zones that are thereby subject to potential losses. Exposure data was collected and compiled in GIS from various sources including Central and State Government Departments, and academic, UN and private organizations. The key exposure elements considered include, people, buildings – residential, commercial and industrial, religious and cultural heritage sites; essential facilities- schools, health facilities; public buildings including government buildings, fire-stations, police stations, and safe shelters; transportation infrastructure including roads, railways, bridges, airport, railways and seaports; utility systems including waste water systems, potable water systems, oil and gas infrastructure, electricity and communication; and critical infrastructure including power plant, hazardous storage and sensitive installation. Major agriculture crops and natural ecosystem (plantation, mangroves) were also considered while compiling the exposure data.

The building locations were derived mainly using satellite images as building clusters for residential, commercial, and industrial buildings. To delineate buildings based on structural details, wall and roof material combinations were derived from Census 2011 at village/ city levels. The Census (2011) provides 90 combinations based on the predominant materials of roof and wall. These combinations have been further grouped into 25 combinations. Out of these 25 combinations, in the study area of Andhra Pradesh and Odisha, mainly six predominant building structural classes are available. These classes were further validated through sample-field verification surveys. Wherever data was not available, accepted proxy data were used. Replacement values of various exposure elements were collected from various organizations and field survey.

Physical and Social Vulnerability

Physical vulnerability functions for various types of buildings and infrastructural components were developed for all three hazards for different structures based on field observations, engineering judgment, and expert opinion. For agriculture, major crops of Kharif season were considered for vulnerability damage functions, which are based on field observation, historical data, and are validated against historical losses.

Social vulnerability analysis was carried out at village level. Index based approach was adopted and key social indicators influencing social vulnerability were considered for developing the Social Vulnerability Index (SoVI).

Key Findings of Exposure and Vulnerability Analysis

The Table E-1 provides details of estimated values for aggregated and site-specific exposures in the study area for Andhra Pradesh and Odisha.

Table E-1: Estimated exposure values for aggregated and site specific exposures

		Andhra Pradesh	Odisha
Sl. No.	**Exposure Layer**	**Total Replacement Cost (in Crores)**	**Total Replacement Cost (in Crores)**
1	Residential	695,804	77,387
2	Commercial	30,688	24,663
3	Industrial	33,440	17,663
4	Educational institutions	30,080	26,860
5	Health facilities	2,880	2,702
6	Religious places	1,950	2,229
7	Police Stations	218	39
8	Fire Stations	22	55
9	Administrative Headquarters	291	166
10	Cyclone Shelters	920	48
11	Airports	2,775	912
12	Bridges	24,803	18,227
13	Railway bridges	4,963	3,063
14	Railway Lines	19,169	4,592
15	Roads	37,587	24,175
16	Sea Ports	20,000	7,600
17	Oil and Gas	4,452	1,584
18	Potable Water	11,801	1,684
19	Waste Water	8,050	2,682
20	Communication System	6,048	4,087
21	Electric Power Network	18,434	10,906
Grand Total		954,375	231,324

- The SoVI map shows high social vulnerability in Krishna, Vishakhapatnam, Vizianagaram and Srikakulam districts. Coastal villages of these districts have a high social vulnerability index, which is mainly attributed to high population density and low density of roads and health facilities. The West and East Godavari and Sri Potti Sriramulu Nellore districts have a majority of the villages with medium SoVI and Prakasam and Guntur have villages mostly with low SoVI. Prakasam district interestingly has all the villages with low SoVI, which means having higher resilience. This is mainly because of low population density and because for livelihood, people are mainly depending on secondary and service sectors.
- The SoVI map of Odisha shows quite a different pattern compared to that of Andhra Pradesh, which is highly influenced by the population distribution. The northern part of

the state – Mayurbhuj and the southern districts - Puri and Cuttack districts have majority of the villages with high SoVI. Bhadrak and Ganjam have relatively less number of villages with high SoVI. Some of the coastal villages of Odisha, particularly, Bhadrak, have coastal villages with a low population density and show a low SoVI. Many of the villages in Odisha have poor road and health facilities, which are driving them for high SoVI. North of Chilka Lake, Puri district has a large number of villages with high SoVI, in which a majority of people's livelihood comes from fisheries.

Risk Assessment Model

Risk is the uncertainty of future losses and loss is the decrease in asset value due to damage, typically quantified as the replacement or repair cost. Direct Loss is a function of the damage ratio derived in the vulnerability module translated into currency loss by multiplying the damage ratio by the value at risk. As stated earlier, deterministic cyclone scenarios were developed for both Andhra Pradesh and Odisha. Direct losses were calculated for every scenario event and for all types of exposure elements at risk. This is done for each asset class at each location where the treatment of location (site-specific exposure - point or line type and aggregate exposure) differs from hazard to hazard and asset class to asset class. Losses were first estimated based on wind, storm surge, and cyclonic rainfall induced flooding from various events. These individual losses were then combined to obtain the composite loss from wind, surge, and cyclonic rainfall induced flood. Losses were then aggregated at administration level (village/city/ mandal/tehsil/ district/ state). Based on the above approach losses were computed for all the exposure elements. For details, the reader is requested to refer to section 5.0 and section 6.0 of this report.

The Probable Maximum Losses (PMLs) are used to identify and prioritize the villages that are under higher risk (hotspot identification). All areas that have high PML are automatic choices for mitigation measures. Similarly, villages/cities that have high SoVI are also under higher risk (hotspot identification). For details, the reader is requested to refer to section 5.4.

As cyclone warning have become very effective in present day India, safe shelters have a very important role in protecting life. The capacity of shelter buildings was assessed against potential affected population to derive the shelter needs. This exercise has been carried out at village level. For details the reader is requested to refer to section 5.3.

Risk Assessment Model Validation and Calibration

Losses were calibrated and validated against historical events, wherever observed loss values were available from wind, storm surge, and cyclone induced rainfall flood impacts. Every cyclone does not result in surge and rainfall induced flooding. Therefore, for validation and calibration, it was important to identify a set of cyclone events that could help validate and calibrate losses due to wind, storm surge, and rainfall induced flooding individually as well as combined. Keeping this in mind, the 2013-cyclonic storm Phailin was used to validate and calibrate the losses from wind, surge, as well as rainfall induced flood as Phailin was associated with strong winds, a decent surge height, and also resulted in rainfall-induced floods. Moreover, its Rapid Damage and Needs Assessment (RDNA, 2013) report is also available. Similarly, estimated numbers due to cyclonic wind speeds and associated storm surges were validated and calibrated against the most recent 2014-cyclonic storm Hudhud (RDNA, 2014). The estimated losses due to cyclone induced rainfall flooding were also validated and calibrated against 2008-deep depression for Odisha; and two historical events, namely, the 2000-depression and 2005-cyclonic storm Pyarr for Andhra Pradesh.

In general, there is a good match in the numbers of damaged buildings, infrastructural elements (despite difference in the study area extent in reported districts). However, modeled loss estimates have large variations from the RDNA reports as losses reported in RDNA reports are based on simplified assumptions. For example, for damaged houses in Cyclone Hudhud (RDNA, 2014), reconstruction cost is taken as Rs. 4.0 Lakhs and Rs 3.0 Lakhs, respectively for urban and rural houses that were fully/severely damaged with an assumed average area of 30 and 22 square meters, respectively. This provides much lower estimates of built-up housing area than actual. Moreover, RDNA (2014) reconstruction cost is only for houses that are fully/severely damaged and these are far lower in numbers than the number of partially damaged houses. For calibration and validation details, the reader is requested to refer to section 5.2.

In this study, loss estimates were carried out for each house that is expected to suffer damage in a deterministic scenario cyclone irrespective of the degree of damage. Moreover, in this study, built-up area estimates are based on high resolution satellite imagery data at cluster level as well replacement costs (per square meter) taken for various types from different authentic sources. Similarly, for other exposure elements, explanations are provided for the differences in loss estimates.

Key Findings

1. From the loss analyses of wind, storm surge, and rainfall induced flooding, it is observed that in severe cyclone to super cyclone scenarios, it is the wind speed that governs the losses. From the analysis of different return period (2,5, 10, 25, 50, and 100 years) scenario losses, losses due to flood hazard contribute more for lower return periods whereas cyclonic wind hazard contributes more for higher return periods.
2. PMLs are insignificant for 2 and 5-year return periods for all three hazards. However, for a 100-year return period scenario, significant combined losses are estimated (Rs. 2,584.62 Crores, Rs. 111.35 Crores, and Rs. 200.42 Crores) for Residential, Commercial, and Industrial buildings, respectively, in Andhra Pradesh. Similarly, in Odisha, combined significant losses are estimated (Rs. 720.49 Crores, Rs. 228.97 Crores, and Rs. 343.26 Crores) for Residential, Commercial, and Industrial buildings, respectively
3. The Industrial losses contribute more in composite losses followed by residential losses due to all three hazards in Andhra Pradesh. However, Residential building losses contribute more to composite losses followed by Commercial building losses for Odisha.
4. Jagatsinghpur is the most vulnerable district of Odisha, due to storm surge hazard in all three occupancy sectors followed by Bhadrak district for Residential and Industrial buildings, and Kendrapara for Commercial buildings. Nellore, Vishakhapatanam, and East Godavari districts are the most vulnerable districts for Residential, Commercial and Industrial buildings, respectively in Andhra Pradesh. Similarly, from cyclonic wind hazard, Jagatsinghpur is the most vulnerable district for all three occupancy types in Odisha.
5. Nellore, Vishakhapatanam and Krishna districts are most vulnerable districts in Residential, Commercial and Industrial sectors respectively in Andhra Pradesh due to cyclonic wind.
6. In Odisha, Jagatsinghpur is the most vulnerable district due to cyclone induced flood hazard for Residential and Industrial buildings, whereas Kendrapara is the most vulnerable district for Commercial buildings.
7. In Andhra Pradesh, Srikakulam is the most vulnerable district due to cyclone induced flood hazard for Residential and Commercial buildings, whereas East Godavari is the most vulnerable district for Industrial buildings due to cyclone induced flooding.

Shelter Need Assessment

- For potentially affected population, we considered all the people living in all kutcha and semi pucca houses taking historical damages into consideration. The shelter gaps at village level for both the States are presented in section 6.5.
- There are several villages, which have potential highly vulnerable populations that could get affected and with inadequate number of shelters. Guntur, Krishna, and West Godavari districts have the highest requirement for shelters, while Srikakulam, Prakasam, and East Godavari districts are relatively better placed.

Identification of Hotspots

- In Andhra Pradesh, 40 cyclone hotspots were identified both in rural and urban areas in the study area of the state, which comprises parts of Krishna, Srikakulam, Vishakhapatnam, and Vizianagaram districts. A majority of the hotspot locations are located in Krishna and Vishakhapatnam districts. For details of various hotspots and their ranking of priority, please refer to Table 6.7.
- In Odisha, 33 cyclone hotspots were identified in coastal rural areas in the study area of the state, which comprise parts of Puri, Cuttack, Jagatsinghpur, Kendrapara and Baleshwar districts. A majority of the hotspot locations are located in Puri, Cuttack, and Jagatsinghpur districts. For details of various hotspots and their ranking of priority, please refer to Table 6.8.

Prototype Web-based GIS Risk Atlas

The prototype web-based GIS Risk Atlas for Andhra Pradesh and Odisha has the functionalities to generate risk reports and maps from all three hazards (Wind, Storm Surge, Flooding) and report composite risk at village/city level by aggregating them at mandal/tehsil/district/state level for the study area for each deterministic scenario event as well as for the six key return period events (2, 5, 10, 25, 50, and 100 years).

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Abbreviations

Abbreviation	Expanded Form
AP	Andhra Pradesh
CWC	Central Water Commission
DEM	Digital Elevation Model
FAO	Food and Agricultural Organization
FSI	Forest Survey Of India
GOI	Government Of India
IMD	India Meteorological Department
INCOIS	Indian National Centre For Ocean Information System
IREE	International Railway Equipment Exhibition
LEC	Loss Exceedance Curve
LULC	Land Use Land Cover
MDR	Mean Damage Ratio
MHA	Ministry Of Home Affairs
MSL	Mean Sea Level
NCRMP	National Cyclone Risk Mitigation Project
NDMA	National Disaster Management Authority
NHAI	National Highway Authority Of India
NHO	National Hydrographic Office
NRSC	National Remote Sensing Centre
pa	Per Annum
PMGSY	Pradhan Mantri Gramin Sadak Yojna
PML	Probable Maximum Loss
PWD	Public Work Department
QC	Quality Control
RCC	Reinforced Cement Concrete
SOI	Survey Of India
SoVI	Social Vulnerability Index
SRSS	Square Root of Sum Of Squares
SRTM	Shuttle Radar Topography Mission
WECC	Western Electricity Coordination Council

1 Introduction

The Indian coast is highly vulnerable particularly to severe cyclone and cyclone induced heavy rain and flooding. An estimated 40% of the total population of the country lives within 100 km of the coast. Keeping these in mind, the National Disaster Management Agency (NDMA) has taken initiatives to develop a proactive approach for integrating disaster risk reduction in development planning.

The National Cyclone Risk Mitigation Project (NCRMP) is a pioneer project of the Ministry of Home Affairs (MHA), Government of India (GOI) and is being implemented through NDMA with the financial support of the World Bank. The aim of NCRMP is to create suitable physical infrastructure to mitigate/reduce the adverse effects of cyclones. Part of this innovative project involves setting up of a web-based Cyclone Risk Atlas that would provide a risk management framework for decision makers in the States/UTs and the Central Government to take mitigation steps to protect the people and assets of the country.

The present report, '*Risk Assessment Report for Andhra Pradesh and Odisha'*, is the sixth deliverable of this assignment, which highlights the risk assessment carried out by RMSI for two pilot states – Andhra Pradesh (AP) and Odisha. The report also includes a section on the *hotspot* areas and their risk maps.

1.1 Objectives of the Study

The objective of the study is to provide a robust scientific and practical basis for assessing the risks from the cyclone hazard for the 13 coastal States/UTs of India. The main objectives of the study include:

- Developing standardized spatial databases, maps and a decision support framework for assessing the cyclone and related hydro-meteorological hazards, exposure, and vulnerability
- Identification of critical *'hotspot'* high vulnerability coastal areas for communities at-risk and detailed development of planning/mitigation and emergency response decision support mechanisms in 10 of the top identified '*hotspot*' areas (enable support for land use planning, shelter locations, evacuation routing, and emergency and contingency planning within these hotspot communities).
- Developing a platform for dynamic risk assessment modeling functionalities that will be taken up subsequently under Phase II of the NCRMP Project (Deterministic hazard and vulnerability data to risk modeling is being done for phase-I (part of this report for Andhra Pradesh and Odisha), Dynamic and Probabilistic risk modeling shall be done for phase-II).

1.2 Study Area and Scope of this Report

1.2.1 STUDY AREA

The study area includes the coastal stretches that lie up to 10 m Mean Sea Level (MSL) in the districts of the 13 States/UTs, which could be vulnerable to cyclone winds, surge and cyclone induced flooding. For the convenience of data access and subsequent project activities, we have considered all the tehsils/mandals/talukas falling within the 10m contours from MSL. Even if only a portion of a tehsil/taluka/mandal lies within the 10 m MSL limit, the entire Taluka has been considered. By this method, the total number of talukas/mandals, having geographical extent up to the 10 m MSL limit, is 617 and the names of these selected talukas are provided in Table 6.1 in Annexure 1 and are shown in Figure 1-1. The total geographical area covered by these talukas/ mandals is around 2,55,000 sq km.

These 13 States/UTs are further classified into two categories, based upon the frequency of cyclone occurrence, size of population and the existing institutional mechanisms for disaster management. The categories are as follows:

Category I: Higher vulnerability coastal States/UTs, i.e., Andhra Pradesh, Gujarat, Odisha, Tamil Nadu, and West Bengal

Category II: Lower vulnerability coastal States/UTs, i.e., Maharashtra, Goa, Karnataka, Kerala, Daman & Diu, Pudducherry, Lakshadweep, and Andaman & Nicobar Islands.

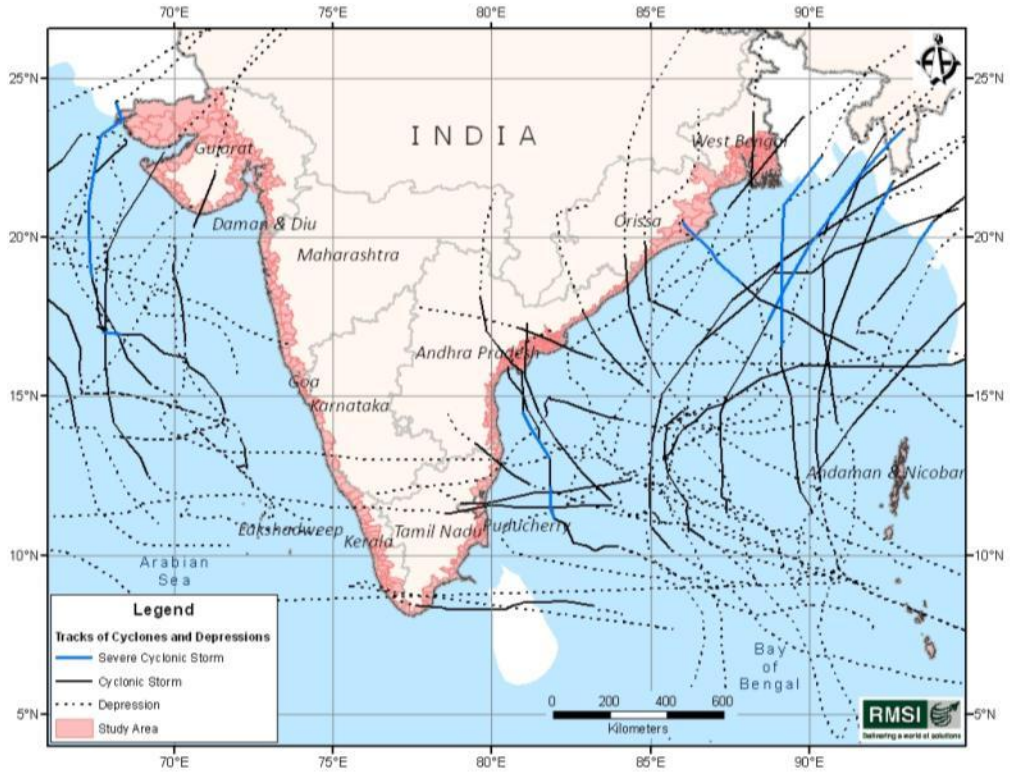

Figure 1-1: Coastal Talukas/Mandals of the 13 states/UTs with land area falling up to the 10m MSL limit along with major cyclone tracks

1.2.2 Scope of this Report

The scope of this report for Andhra Pradesh and Odisha includes:

- Results of quantified risks (socio-economic damage and losses) from the impacts of scenarios. Overall, and disaggregated administratively, geographically, sectorally, socially and by elements of the built and natural environment as appropriate to serve NDMA and coastal States/UTs government agencies' and communities' needs. Input data and analysis results are provided in a GIS package to permit use by governmental agencies and others to derive results specific to their needs.
- Development of hotspot risk maps based on hazard, exposure and risk assessment
- Status of the progress on Cyclone Hazard Web-GIS Risk Atlas.

In addition to this, we also have provided an overview of the hazard mapping, exposure data and vulnerability analysis that was detailed in the earlier deliverables, which make it easy for readers to refer to the inputs (hazard, exposure, and vulnerability) we have used for the risk assessment.

1.3 Overview of Risk Analysis

Risk is the uncertainty of future losses – if we perfectly know a future loss, it is simply a cost, not a risk. Risk is uncertain with regard to causative hazard (e.g., cyclone, flood, etc), location, date and time of occurrence, the degree or amount of damage to assets caused by the hazard, and what losses accrue due to the damage. Note that damage and loss are distinguished – in fact, a few terms are worth defining here:

- **Risk**: uncertainty of future losses
- **Loss**: decrease in asset value due to damage, typically quantified as the replacement or repair cost.
- **Damage**: physical degradation of an asset (e.g., collapse of a building)
- **Asset**: what we value – examples include a building, the people inside, the furniture and other contents of the building. Asset values typically are measured in terms of deaths and injuries, monetary value, and temporal duration of disruption ("deaths, Rupees and duration").
- **Exposure**: the geographical distribution and/or total of asset values
- **Hazard**: damaging natural phenomena such as cyclone, flood, earthquake, tsunami, landslide, etc.
- **Hazard intensity**: the intensity and distribution of damaging effects caused by a hazard (e.g., the distribution of the depth of water in a flood).

The risk analysis process is depicted in Figure 1-2, where it can be seen that: (1) a region of interest is selected, for which (2) the hazard is determined, based on data and the physics of the earth. Next, (3) the assets at risk are 'overlaid' on the hazard – that is, the intensity of the hazard is correlated with the location of the assets, based on which (4) damage is determined, based on the engineering principles and the attributes of the assets. Lastly, (5) losses are calculated based on the damage.

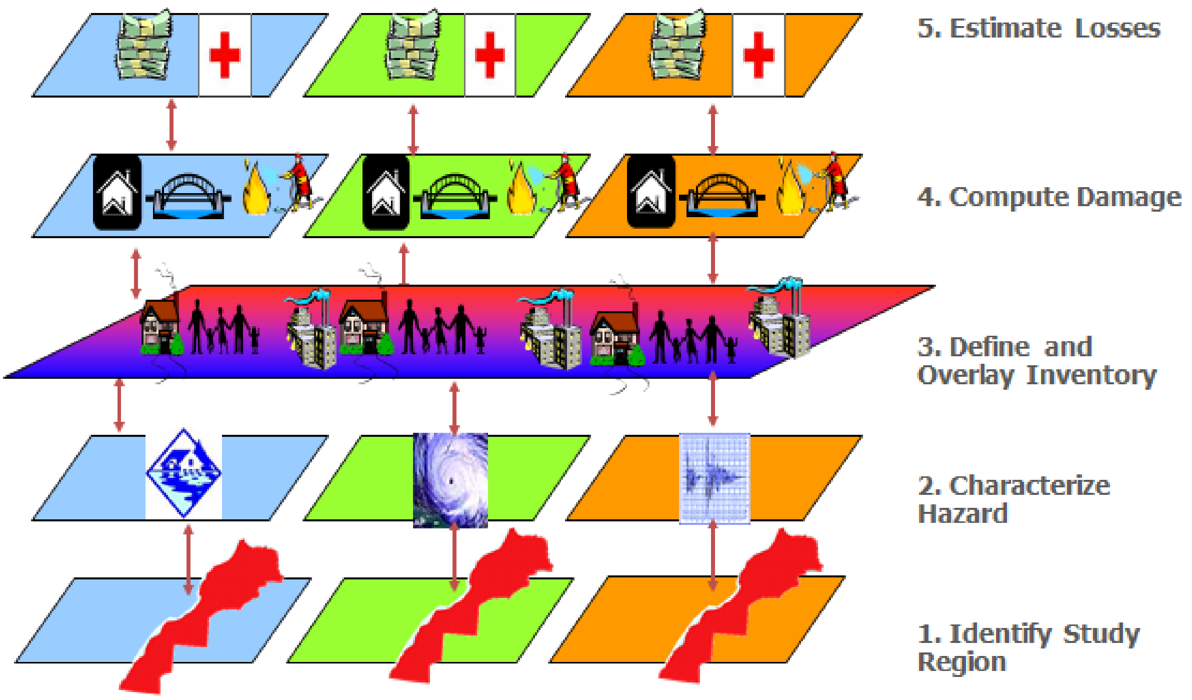

Figure 1-2: Risk Analysis process

Since risks are uncertainty of future losses, they must be stated through probabilistic scenarios that provide a return period loss. By "20 year loss" we mean a loss that will occur on average about once every 20 years, given what we know about hazards, exposure etc. Such a "20 year loss" in actuality has a 1/20 = 0.05 probability of occurrence in any one year, and two such losses can occur at times more frequently than 20 years (in fact, two such losses could occur in the same year). Similarly, a "500 year loss" has probability per year (or "per annum", pa) of 1/500 = 0.002.

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1.4 Organization of this report

This report is organized under the following key chapters:

1. Introduction: Provides a brief background of the project, scope of this report, and an overview of risk analysis. The overview of the risk analysis primarily aims to introduce the terms and how the terms are applied in the analysis
2. Overview of hazard assessment: This section provides the summary of hazard assessment carried out for cyclonic wind, storm surge and cyclone induced flooding, which is one of the key inputs of the risk assessment. For details, please refer to the Hazard Assessment Report.
3. Overview of exposure data development: This section provides an overview of the exposure data developed for the analysis of the risk assessment. For details, refer to the Exposure Data Development Report.
4. Overview of vulnerability function development: provides an overview of the vulnerability analysis, which helps assess the impact of the hazard on the exposure element.
5. Risk assessment methodology: This section provides the methodology adopted for carrying out the risk assessment including the details of the methods adopted for analyzing shelter needs and identification of hotspots.
6. Key findings: This section provides the risk assessment results, outcome of shelter need analysis, and the hotspots identified for both the states. The risk assessment results are presented by state and sector.
7. Status of Progress on Web-GIS Risk Atlas Development: This section provides the status of development of the Web Risk Atlas.
8. Annexure: This section provides additional information like detailed losses at district and sub district levels for further reference.

2 Overview of Hazard Assessment

This section provides the summary of hazard assessment carried out for the cyclonic wind, storm surge and cyclone induced flooding which was provided in detail in the "Hazard Assessment Report for Andhra Pradesh and Odisha" delivered earlier.

Historical Review, and Hazard Data Collection and Processing

As a first step, the team carried out a thorough review of historical cyclones and cyclone induced flood events. A historical cyclone event catalog was created using four different sources as shown in the table below. All the events were classified as per the IMD storm classification scheme.

Table 2-1: IMD's storm classification scheme

Sl. No.	Thematic data	Data source	Data availability
1	Storm Track Atlas	IMD	Cyclone track data for 1891-2007 is available in CD version (2008 ed.)
2	Historical cyclone track data	IMD	Cyclone track data for 1990-2014 is available at IMD website (www.imd.gov.in)
3	Historical cyclone track data	IBTrACS	Cyclonic database is available on public domain at six hourly intervals from 1842-2014
4	Historical cyclones maximum winds, Surge height, extent of inundation and flood depths along with associated loss information	SMRC report (1998), and published literature	IMD reports, SMRC report (1998), and published literature and research publications are available in public domain

A frequency and severity analysis of the historical cyclone catalog from 1877 to 2014 revealed that the Indian coastline can be divided into 5 severity zones varying from very high to low severity zones. Accordingly, the coasts of West Bengal and Odisha come under the very-high severity zone (Zone 1), that of Andhra Pradesh under the high severity zone (Zone 2), while the coasts of Tamil Nadu, Karnataka, Maharashtra, and Gujarat (Zone 3 and 4)come under the moderate severity zone, and Kerala comes under the low severity zone (Zone 5).

Historical data analysis shows that 202 cyclonic events made landfall in Zone 1 on coastal West Bengal and Odisha, an average of less than 2 cyclones per year and 103 cyclonic events crossed Zone 2 on Andhra Pradesh out of 176 cyclonic disturbances, an average of 1 cyclone per year. Out of these, 55 and 47 very severe cyclonic storms hit the Zone-1 and Zone-2 respectively during the period of 138 years.

Cyclone is a complex natural phenomenon that needs several parameters to model accurately. In order to model cyclone winds and surge, and cyclone rainfall induced flooding, the team collected Bathymetry (GEBCO and NHO), Topography (SRTM and NRSC DEMs) data, Meteorological rainfall (IMD) data, Hydrological flow (CWC) data, Land Use Land Cover (high resolution satellite data), and Soil (FAO) data. Data cleaning was performed by a series of quality control (QC) checks to identify missing values and to flag suspected values. Two types of data validations were carried out, namely, replacement of erroneous values and supplementing missing values using standard and internationally accepted processes.

Cyclone and storm surge modeling

All the historical cyclones that had made landfall in Zone 1 and Zone 2 were considered for identification of deterministic scenarios. The depressions and deep depressions were grouped in representative groups and two to three events from each group were selected. All the other category cyclones, i.e., Cyclone Storms, Severe Cyclonic Storms, Very Severe Cyclonic Storms, and Super Cyclonic Storms were included in the deterministic scenario list for analysis. This gave a total of 350 events in Zone 1 for Odisha and 160 events in Zone 2 for Andhra Pradesh.

Surface winds associated with a tropical cyclone are derived using a dynamic storm model. A variable pressure deficit, forward speed, and radius of maximum winds have been used in the storm model for computing wind fields at model grid points over the study area.

Storm-surge hazard modeling was performed using the ADCIRC-2DDI model. The ADCIRC model requires wind forcing which was taken from the wind field derived using the dynamic storm model. Water levels along the open boundary were obtained from global tidal information from FES2004 database. ADCIRC provides surge amplitudes and associated inland inundation and flow velocity over the model domain.

Both the models were validated and calibrated against key historical cyclones using the observed data associated to those historical events. The calibrated models were used to generate the estimates of wind speeds and surge heights associated to every historical event at model grid points over the study area. The Gumbel's extreme value probability distribution was applied to modeled wind speeds and surge inundation depths to derive additional deterministic scenarios of maximum wind speeds for key return periods (2, 5, 10, 25, 50, and 100 years). These were summarized using GIS techniques to create return period scenario maps at village level.

Cyclone Induced Rainfall Flood Modeling

The flood modeling assesses the flood hazard associated with rainfall generated by cyclones for the study area. Flood hazard has been assessed for major river systems across the study area (Subarnarekha, Brahmani Baitarani, Mahanadi, Godavari, Krishna, and Pennar river basins) to estimate the potential inundation from cyclone induced rainfall. A deterministic approach has been used to combine the information on (1) the scenarios of flooding, (2) the spatial extent of floods for different severity levels, and (3) the consequences of these floods (e.g. inundated area and flood depth).

As a first step, cyclone generated rainfall/flow events have been extracted by reviewing rainfall/flow information associated to the cyclone. Based on this review, ninety-four events in Odisha and 92 events in Andhra Pradesh have been catalogued and have been used for historical flood events simulation and estimation of deterministic scenarios. For all rainfall-based events, hydrologic modeling was performed to generate flows followed by hydraulic modeling, whereas, hydraulic modeling was done direct for all flow-based events.

A hydrological model establishes the flow behavior of the watershed or basin by converting the rainfall into runoff. The team used the open source hydrological model HEC-HMS. It transforms digital terrain information like drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation, thus estimating the flows at various locations along the path of the river. The model was calibrated and validated using observed flow data by generating the flow hydrographs at various gauge stations and comparing the peak flows from multiple historical events.

Finally, two dimensional (2-D) hydraulic model development was undertaken to route the flows from one location to another, while estimating the water surface elevations and profiles for various scenarios. The 2D hydraulic model developed by the USACE HEC-RAS has been used for predicting and understanding the floodplain inundation process. The model was calibrated and validated using observed water level data at various gauge stations from multiple historical flood events.

Using the river discharges during the various cyclonic events, the boundaries of the flood plains were determined by using HEC-RAS 2D to provide flood extent maps that integrated model results with elevation data.

Observed cyclonic peak flows and simulated cyclonic peak flows were used for deterministic events generation for key return periods (2, 5, 10, 25, 50, and 100 years) for the gauge stations of various rivers. The key return period values of cyclonic peak flows were estimated using multi-variate extreme value distribution analysis using the Gumbel's Generalized Extreme Value Distribution. The estimated key return period flows were used as an input to the hydraulic model for flood plain delineation. The flood hazard maps were generated for the historical and deterministic events for key return periods (2, 5, 10, 25, 50, and 100 years).

Major Findings for cyclone, storm surge, and cyclone induced rainfall hazards

- Analysis of historical cyclonic events across all five Zones indicates that the frequency of Very Severe Cyclonic Storms is higher than the Severe Cyclonic Storms. This is contrary to the normal behavior of hazards as per which the stronger events are rarer. This suggests that the potential for more frequent larger losses in India is higher.
- Comparing severity of Zone-1 and Zone-2, one observes that the total number of cyclones that have hit Zone 1 is much higher than Zone 2 indicating that the risk is much higher in Zone 1 than in Zone 2. However, another interesting finding is that 13 severe cyclonic storms struck the Zone-2 whereas Zone-1, which comes in very-high severity zone, has been affected by only 8 severe cyclonic storms. This suggests that the potential for more frequent moderate losses is high in Zone-2 as compared to Zone-1.
- It is observed from modeling cyclone-induced rainfall that it is the translational speed of the cyclone that plays an important role in flooding. Slower moving cyclones cause more flooding irrespective of their strength.
- In case of both Odisha and Andhra Pradesh, the modeling of flood events reflects specific discharge thresholds beyond which flooding is sure to happen. The trigger discharge values for various rivers at various gauge locations are given below.

River	Gauge	Discharge, cumec
Mahanadi	Tikarpara	10,000
Brahmani	Jenapur	3,000
Baitarani	Anandpur	1,500
Subernarekha	Ghatsila	2,000

River	Gauge	Discharge, cumec
Pennar	Nellore	1,500
Godavari	Polavarm	12,000
Krishna	Vijaywada	9,000
Vamsadhara	Kashinagar	1,500
Nagavali	Srikakulam	1,500

Findings for Andhra Pradesh

- In Andhra Pradesh Guntur, Krishna, and Srikakulam could experience winds of about 128-136 km/h under a 100-year return period scenario. The most vulnerable low-lying areas of Guntur and Krishna are prone to high water levels due to storm surge flooding.
- In Andhra Pradesh, cyclone induced flooding is mainly due to flooding in the small east flowing rivers, as the discharge carrying capacity of these rivers is comparatively low.
- In Andhra Pradesh, the coastal region of East Godavari district and the delta region of the Krishna and Guntur districts are highly affected due cyclone induced flooding. However, the Prakasham and Nellore districts get flooded due to Pennar and other rivers with smaller flows.

Findings for Odisha

- In Odisha, the delta region of Mahanadi and Brahmani-Baitarani rivers and in Andhra Pradesh the delta region of Krishna and Godavari rivers is highly vulnerable due to cyclone-induced flood.
- The Jagatsinghpur, Kendrapara, and Ganjam districts of Odisha are more vulnerable to cyclonic wind hazard with Jagatsinghpur being most vulnerable to strong winds of about 144 km/h. Northern Odisha is more prone to cyclone surge with average flood depth for 100-year return period event varying between 0.5 to 5.6 m. The Puri and Ganjam districts are less prone to storm surge with average flood depths ranging around 0.5 to 4.0 m for a 100-year scenario.
- In Odisha, Kendrapara, Bhadrak, Baleshwar and Jajpur districts are the most affected due to cyclone induced flooding. This region gets heavily flooded even due to a marginal increase in river flows. However, Puri and Jagatsinghpur districts are less affected due to cyclone induced flooding with the exception of a few village pockets.

3 Overview of Exposure Data Development

This section provides an overview of the exposure data developed, the details of which were provided as part of the "Exposure and Vulnerability Assessment Report for Andhra Pradesh and Odisha" delivered earlier.

Introduction to Exposure Data Development

Exposure is a critical component of any risk model. Exposure constitutes the population, the built environment, the infrastructure, and/or any other elements present in hazard zones that are thereby subject to potential losses.

The initial steps in exposure development are data collection and processing of the collected data. The main elements of exposure in this study are population and households, residential buildings, and other non-residential buildings that include commercial, industrial, religious and cultural heritage sites. Apart from these, infrastructural facilities have been considered under five broad headings, namely essential facilities (schools and health facilities), public buildings (administrative headquarters, fire-stations and police stations), transportation system (roads, railways, bridges on roads and railways, airports and seaports), utility systems (waste water and potable water systems, oil and gas infrastructure, electricity and communication), and critical infrastructure (power plants and sensitive installation). Besides these, to assess the impacts of cyclone, storm surge, and cyclone induced rainfall flooding, a database of crops, coastal plantations, and mangroves has also been compiled as a part of exposure development.

Figure 3-1 shows the broad categories of exposure elements that have been considered in this study.

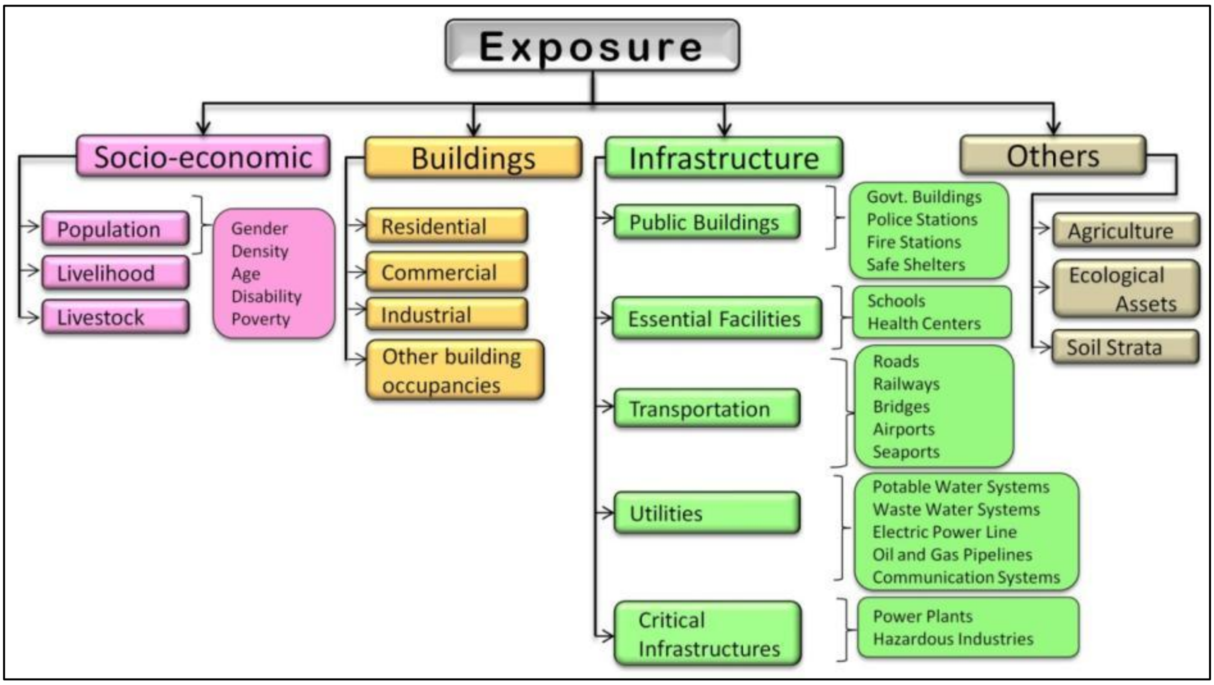

Figure 3-1 Categories of exposure elements

The key data sources used in developing the exposure database are as follows:

- Survey of India (SOI) for administrative boundary and site specific data
- Census of India (2011 vintage) for population at ward/village level, housing tables in absolute numbers at city level in urban areas and at district levels for rural areas;

housing tables in percentage at ward- and village-levels, and occupancy tables at city level in urban areas and at district levels for rural areas
- Forest Survey of India (FSI) for coastal plantations and mangroves data
- Department of Agriculture and Cooperation, Ministry of Agriculture for agriculture data
- State departments for state-specific data
- RMSI in-house data and online sources to fill the gaps in the existing data

Exposure and vulnerability assessment also focuses on establishing a relationship between the potential damageability of critical exposure elements and different levels of hazard intensity for the hazards of interest in this study through physical vulnerability analysis. Physical vulnerability refers to the degree to which an asset would undergo damage or be destroyed in a hazardous environment caused by catastrophic events. Physical vulnerability assessment involves quantifying the damage susceptibility of each asset class with respect to hazard parameters of each hazard. On the other hand, social vulnerability refers to the incapability of people, organizations, and societies to endure adverse impacts from disasters to which they are exposed.

Damage susceptibility associated with a given level of hazard is measured in terms of a mean damage ratio (MDR) defined as the expected proportion of the monetary value of repair needed to bring back the facility to pre-event condition, over the replacement value of the facility, as a consequence of the hazard. The curve that relates the MDR to the hazard is called a vulnerability function. Vulnerability functions have been developed for various assets for different hazards, using analytical/synthetic and statistical methods complemented with expert engineering or heuristic judgment based on local and/or international experiences.

Key Findings on Exposure Data Development

The important step in exposure development is to analyze the processed data for gaps and to use time-tested methods to fill the identified gaps. Based on the gaps identified, appropriate approaches are applied. The major gaps could be categorized into missing location information, missing building typology, missing replacement costs, and in certain cases, a complete lack of data regarding particular exposure types.

The demographic data is available at ward/village level. Using the population growth rate, the population data of 2011 is projected to year 2014 for urban areas at ward and city levels (however, due to non-availability of ward level boundaries, the analysis is restricted to city level) and at village level for rural areas.

Similarly, 2011 household information providing the details of number of households is also projected to 2014. Finally, all the data is compiled for developing the demographic exposure database.

RMSI's approach for quantifying building exposure is based on the "bottom-up" approach. This includes classifying the different types of buildings into different categories, estimating the number of buildings under each category, combining building counts with per unit built-up floor area, and applying costing information relevant to the conditions. The output of building exposure is the total monetary value by asset category.

Data provided by the Census of India (2011) based on occupancy type is limited to building counts at city/district level. As a result, the quantification of exposure data pertaining to buildings became a challenging and complex process mainly because of missing location information and unavailability of replacement costs of each of the identified typologies.

The building location information is derived mainly using satellite images as building clusters for residential, commercial, and industrial buildings. To delineate buildings based on structural details, the team considered the wall and roof material combinations derived from Census 2011 at city/village level. The Census (2011) provides 90 combinations based on the predominant materials of roof and wall. These combinations have been further grouped into 25 combinations based on the vulnerability of buildings to different hazards. Table 3-1 presents the six predominant building structural classes that are mainly available in the study area of Andhra Pradesh and Odisha. All these structural classes have been validated through sample-field verification surveys and considered for customizing the vulnerability functions.

Table 3-1: Predominant building structural categories by construction materials

Sl. No.	Building Category	Structural Types (combination of major wall and roof materials)
1	ST4	Grass/ thatch/ bamboo/ wood/ plastic/ polythene etc. used as roof material in combination of burnt brick/ stone packed with mortar/concrete as wall materials
2	ST6	Handmade tiles/ machine made tiles/burnt bricks/stone/slate/concrete used as roof material in combination of Grass/thatch/bamboo etc. as wall material
3	ST8	Handmade tiles/ machine made tiles used as roof material in combination of stone packed with mortar/burnt brick/concrete as wall material
4	ST16	G.I./Metal/Asbestos sheets used as roof material in combination of Stone packed with mortar/ burnt brick/ concrete as wall material
5	ST17	Concrete used as roof material in combination of Mud/unburnt brick/Stone not packed with mortar as wall material
6	ST18	Concrete used as roof material in combination of Burnt brick/Stone packed with mortar/Concrete as wall material

Based on the unit replacement cost provided by Central Public Works Department (2012) Andhra Pradesh Municipal Asset Methodology Valuation Manual (2012), National Municipal Asset Valuation Methodology Manual (2007) and inputs from RMSI field sample verification survey (2015), unit replacement cost of buildings for each occupancy/structural types has been derived. Finally, after careful review and analysis by RMSI expert team, the average unit replacement costs for each type of buildings has been derived.

SOI and online sources have been used for police stations data in the study area. The data gaps are primarily in the areas of structural types, floor area, and replacement costs that were filled using literature survey, sample field-verification survey, and secondary data. The source of data for fire stations is the State Fire Service and emergency services. The data gap for fire stations is primarily in the area of replacement costs that are filled-in using literature survey, sample survey, and secondary data.

The data that could be collected for administrative headquarters and cyclone shelters is also patchy (lack geospatial location and building attributes). Using online sources, a list of administrative headquarters in the study area has been compiled for Andhra Pradesh. In the absence of exact spatial data for administrative headquarters, point data has been generated at city/town level. Similarly, using Revenue Disaster Management, Govt. of Andhra Pradesh[1] website, data for 1,000 shelters has been downloaded for Andhra Pradesh. Out of these, 234 cyclone shelters could be geocoded at village level. In Odisha, the data for cyclone shelter received from Odisha revenue and disaster management department. This data contains 134-cyclone shelters geospatial location. The data lacks structural details, floor area, and capacity that were filled using literature survey, sample survey, and secondary sources including NDMA NCRMP website.

For transportation infrastructure, the prime source of data is SOI. The data gaps have been filled using RMSI in-house data, high-resolution satellite images, and online sources. In order to estimate the replacement costs, unit costs of various components of transport infrastructure were determined by taking inputs from the Pradhan Mantri Gramin Sadak

[1] http://disastermanagement.ap.gov.in/website/shelters.htm

Yojna (PMGSY)[2], National Highway Authority of India (NHAI)[3], Public Works Department (PWD)[4], International Railway Equipment Exhibition (IREE)[5], Indian Railways[6] website, and Planning Commission. In order to estimate the replacement costs of airports, unit cost of the built-up area as well as the unit cost of the runway was determined by taking inputs from online sources (Airport technology.com)[7]. For estimating the replacement costs of seaports, cost for developing one berth of the port was determined from online sources.

In the Utilities category, the spatial data for wastewater and potable water systems is not available from any of the sources. Census (2011) provides village-level percentage of household having open and closed drainage systems and tap water from treated and untreated sources. Using these percentages, approximate lengths of wastewater and potable water systems has been estimated using the road network data assuming that drainage network is distributed along the roads.

In the case of communication infrastructure, city and village level data on the number of mobile and landline connections are available. The exposure value of communication systems has been estimated using the number of mobile and landline connections in the study area.

The electric line network has been received from SOI but it lacks continuity and details of electric sub-stations, as well as having a bit older vintage of 2005 or earlier. Therefore, using data present in the open street map, data gaps for electric transmission lines have been filled. In order to estimate the replacement cost of the electric power network, unit cost of the electric lines has been determined by taking inputs from the Western Electricity Coordination Council (WECC).

None of the sources has provided data for oil and gas pipeline. Therefore, a map of India Energy Infrastructure[8] from online sources has been used as reference. This map has spatial distribution of the oil and gas infrastructure in India. The length of oil and gas pipelines has been estimated based on this map in the study area of Andhra Pradesh and Odisha. In order to estimate the replacement cost of the oil and gas pipeline network, unit cost of oil and gas pipelines has been determined by taking inputs from open sources[9].

Critical infrastructure consists of power plants and sensitive installations. Data for power plants and sensitive installations have been developed using online sources[10]. Using high-resolution satellite images, power plants and sensitive installations have been captured as point locations. The list of major and hazardous industrial facilities has been taken from Andhra Pradesh pollution control[11]website. For Odisha, the list of major and hazardous industrial facilities has been taken from Ministry of Labor and Employment, Government of India website. Using high-resolution satellite images, major and hazardous industrial facilities, power plants, and sensitive installations have been captured as point locations. The exposure value of Critical infrastructure has been taken from a few online sources.

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[2] http://pmgsy.nic.in/achiev_bhanirm.htm
[3] http://www.nhai.org/completednh2.asp
[4] ttps://pwddelhi.com/UI/Home/SectorWiseReport.aspx?enc=9J3T0Ky+opEjCrT08q8UfA
[5] http://www.ireeindia.org/RE%20Booklet.pdf
[6] http://www.nr.indianrailways.gov.in/view_detail.jsp?lang=0&dcd=3265&id=0,4,268
[7]http://www.airport-technology.com/projects/indira-gandhi-international-airport-terminal-3/

[8] http://www.eia.gov/todayinenergy/detail.cfm?id=10611

[9] http://www.yourarticlelibrary.com/india-2/pipeline-6-major-pipelines-of-india/19721/

[10] http://www.apgenco.gov.in , http://www.gvk.com/ http://www.spgl.co.in/

http://www.meenakshigroup.com

[11] http://www.appcb.ap.nic.in/main/index_flat1.php

Data for major agriculture crops constitute one of the primary exposure elements. Due to unavailability of village-level crop data, district level crop data (source: Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India) are disaggregated at village level using Land Use Land Cover (LULC) maps of LISS III satellite data available in-house. Fraction of agricultural area in each village with respect to district level total agricultural area is calculated and subsequently district-level total observed normal acreage is distributed among the villages as per this fraction.

GIS data for coastal plantations and mangroves has been received from FSI, which is of 2013 vintage.

The Table 3-2 provides details of estimated values for aggregated and site-specific exposures in the study area for Andhra Pradesh and Odisha.

Table 3-2: Estimated exposure values for aggregated and site specific exposures

		Andhra Pradesh	Odisha
Sl. No.	Exposure Layer	Total Replacement Cost (in INR crores)	Total Replacement Cost (in INR crores)
1	Residential	696,306	77,387
2	Commercial	30,688	24,663
3	Industrial	33,440	17,663
4	Educational institutions	8,534	5,232
5	Health facilities	31,885	9,861
6	Religious places	1,950	2,229
7	Police Stations	218	39
8	Fire Stations	22	55
9	Administrative Headquarters	291	166
10	Cyclone Shelters	920	48
11	Airports	2,775	912
12	Bridges	24,803	18,227
13	Railway bridges	4,963	3,063
14	Railway Lines	19,169	4,592
15	Roads	37,587	24,175
16	Sea Ports	20,000	13,600
17	Oil and Gas	4,452	1,584
18	Potable Water Systems	11,801	1,684
19	Waste Water Systems	8,050	2,682
20	Communication System	6,048	4,087
21	Electricity Lines	783	529
Grand Total		944,685	212,478

4 Overview of Vulnerability Function Development

This section provides an overview of the vulnerability analysis, which helps assess the impact of the hazard on the exposure element. The details of the vulnerability function development have been provided in the "Exposure and Vulnerability Assessment Report for Andhra Pradesh and Odisha" delivered earlier.

Development of vulnerability functions for various exposure elements is a critical component of any risk assessment study. Modeling vulnerability of a system to natural hazards involves establishing a relationship between the potential damageability of critical exposure elements and different levels of local hazard intensity for the hazard of interest.

Vulnerability can be divided into two broad classes:

- Physical vulnerability
- Social vulnerability

Physical vulnerability refers to the degree to which an asset would undergo damage or destroyed in a hazardous environment caused by catastrophic events.

Social vulnerability refers to the incapability of people, organizations, and societies to endure adverse impacts from disasters to which they are exposed.

4.1 Physical vulnerability function development

Damage susceptibility associated with a given level of hazard is measured in terms of a mean damage ratio (MDR) defined as the expected proportion of the monetary value of repair needed to bring back the facility to pre-event condition, over the replacement value of the facility, as a consequence of the hazard. The curve that relates the MDR to the hazard is called a vulnerability function. Vulnerability functions are developed for various assets for different hazards, using analytical/synthetic and statistical methods complemented with expert engineering or heuristic judgment based on local and/or international experiences.

The focus of development of vulnerability functions is to estimate MDR values corresponding to different levels of hazard intensity (cyclonic wind, storm surge (velocity, inundation), and cyclone induced rainfall flooding depth) for each exposure element considered in this study.

Development of physical and social vulnerability functions for all the 13 States/UTs is mainly, but not solely, based on damage data from historical events. Generally, an analytical approach complemented by engineering analyses along with expert judgment based on national/international experience helps in developing vulnerability functions. For this, RMSI team carried out detailed literature survey for related material to buildings performance in India, abroad, and our engineering judgment.

For cyclone hazard, there are three collateral hazards that can happen in isolation or in combination:

- CP: Cyclone Pressure (measured by wind speed)
- CI: Cyclone induced Inundation (inland-flooding, by depth)
- Ds: Storm Surge- further decomposed into two components
    - SI: Surge Inundation (measured by depth)
    - SM: Surge Momentum (measured by velocity)

  $Ds = (D^2_{SI} + D^2_{SM})^{1/2}$

The final damage states are calculated per SRSS (Square Root of Sum of Squares), as follows: $Dfinal = sqrt \{(D^2_{CP} + D^2_{CI} + D^2_{S})\}$

For each of the above collateral hazards, subsequent sections are given for respective damage functions.

4.2 Vulnerability of crops to cyclone

In the event of cyclones, crops get affected due to flooding and wind speed. The impact of flooding and wind speed on the various crops has been described in the below given sub-sections.

4.2.1 CROP VULNERABILITY TO FLOODING

Most crops grown in India are intolerant to flooding. However, the tolerance level of crops varies. Very susceptible crops include potatoes, pulses, and beans, which may succumb even to one day of submergence under water. In addition, it is critical for many crops at what growing stage they are under submergence conditions. It is to note that only Kharif crops were considered in this study based on the last 117-year database of cyclone events that occurred in the months of May, June, October, and November only (Jain et al. 2010[12]). Hence, cyclone causes damage to crops grown only during the Kharif season. During Kharif season, rice accounts for about 70% of total acreage in the costal districts of Andhra Pradesh and major crops cultivated in the remaining 30% area are groundnut, cotton (lint), maize, and pigeon pea. Similarly, in coastal districts of Odisha, rice accounts for about 85% of total acreage during Kharif season and major crops grown in the remaining 15% area are green gram, black gram, horse gram, and pigeon pea.

Among the above-mentioned crops, rice can survive submergence conditions up to 5-7 days whereas maize can survive flooding for 2-4 days. Major pulses, which are grown during monsoon season, are green gram, pigeon pea, and black gram. All the pulse crops are extremely sensitive to flooding when compared to cereal crops. Furthermore, research in flooded cropland has shown that the oxygen concentration approaches zero after about 24 hours (Weijun Z. et al., 1995[13]). Without oxygen, the plant cannot perform critical life sustaining functions, such as root respiration, and nutrient and water uptake due to impaired roots. Even if flooding does not kill plants completely, it may have a long-term negative impact on crop performance. Besides, submergence also leads to the accumulation of compounds like CO_2, which are toxic to plants in high concentrations (Ashipala, 2013[14]). For the present risk assessment exercise, flood damage function at different flood depths for the crops have been developed using an analytical approach (i.e., using field observations and crop simulation modeling techniques) and applying national/international field experiences. Figure 5-23 shows the relationship between floodwater heights and production losses for major crops grown in coastal districts of Andhra Pradesh and Odisha.

[12] Jain, I., Rao, A.D., Jitendra, V., And Dube, S.K. (2010). Computation of expected total water levels along the east coast of India. Journal of Coastal Research, 26(4), 681–687. West Palm Beach (Florida), ISSN 0749-0208.

[13] Weijun Zhou, Linb X. 1995. Effects of water logging at different growth stages on physiological characteristics and seed yield of winter rape Brassica napus.

[14] Ashipala, S. N. (2013). Effect of climate variability on pearl millet (Pennisetum glaucum) productivity and the applicability of combined drought index for monitoring drought in Namibia. Department of meteorology, college of biological and physical science, University of Nairobi.

4.2.2 CROP VULNERABILITY TO WIND SPEED

High wind is the most common and visual effect of cyclones. For the present risk assessment exercise, wind damage functions at different wind speeds for the crops have been developed using an analytical approach (i.e., using field observations and crop simulation modeling techniques) and applying national/international field experience

4.3 Social Vulnerability Analysis

Social vulnerability refers to the socio-economic and demographic factors that affect the resilience of communities. Studies have shown that in disaster events the socially vulnerable people are more likely to be adversely affected.

Social vulnerability is partly an outcome of aspects of social setup that influence or shape the susceptibility of various factions of the society to disasters and drive their ability to respond. It is, however, crucial that social vulnerability is not considered as a function of exposure to hazards alone, but also the sensitivity and resilience of the society to prepare, respond, and recover from disasters. Social vulnerability is a culmination of economic, demographic, and housing characteristics that influence a community's resilience to natural hazards. The major components of vulnerability are well being, livelihood resilience, skills awareness, social security, and social awareness.

An index-based approach is used to assess the social vulnerability at mandal/tehsil level through development of social vulnerability index (SoVI).

Some of the districts - particularly Krishna, Vishakhapatnam, Vizianagaram and Srikakulam districts have high SoVI. Coastal villages of these districts are showing high index and is mainly attributes to high population density and low density of infrastructure - roads and hospitals. The West and East Godavari and Sri Potti Sriramulu Nellore districts has majority of the villages with medium SoVI and Prakasam and Guntur has villages mostly with low SOVI. Prakasam district interestingly has all the villages with low SoVI, which means high resilience. This is mainly because of low population density and occupational structure. Substantial share of the population are involved in secondary and service sector.

The SoVI distribution is quite different compared to that of Andhra Pradesh, which is highly influenced by the population distribution. The northern part of the State - Mayurbhanj and Puri and Cuttack districts has majority of the villages with high SOVI. Bhadrak and Ganjam have relatively less number of villages with high SoVI. Some of the coastal villages of Odisha, particularly Bhadrak, have coastal villages (villages with seacoast) with low population density and are showing low SoVI. Many of the villages in Odisha have poor road and health facilities, which are key reasons for having high SoVI. North of Chilka Lake, parts of Puri district have a large number of village predominantly engaging in fisheries and have high SoVI.

5 Risk Assessment Methodology

This section explains the methodology used for risk assessment, shelter needs assessment, and hotspot identification.

5.1 Methodology for Loss Estimation

As discussed in the overview of risk analysis, risk is the uncertainty of future losses and loss is the decrease in asset value due to damage, typically quantified as the replacement or repair cost. Loss estimation is the last step in risk analysis.

Direct Loss is a function of the damage ratio derived in the vulnerability module translated into currency loss by multiplying the damage ratio by the value at risk.

L = MDR(j,h) * Value_At_Risk(j) **Equation 1**

where:

MDR(j,h) = Mean Damage Ration for a exposure type 'j' at a specific hazard intensity 'h'

Value_At_Risk(j) = Replacement cost of the exposure type 'j'

As discussed in the hazard section, deterministic cyclone scenarios were developed for both Andhra Pradesh and Odisha. Direct losses are calculated for every scenario event and for all types of exposure at risk like residential, commercial, industrial buildings, essential facilities, infrastructure, and agriculture. This is done for each asset class at each location where the treatment of location differs from hazard to hazard and asset class to asset class. Losses are then aggregated at administration level of resolutions (village/city/ mandal/tehsil/ district/ state) as required.

L(i, j) = MDR(j,i,h) * Value_At_Risk(j) **Equation 2**

where:

MDR(j,i,h) = Mean Damage Ration for exposure type 'j' at a hazard intensity 'h' for event i

Value_At_Risk(j) = Replacement cost of the exposure type 'j'

Based on the above approach losses were computed for all the exposure elements. As discussed in the exposure section, various exposure elements have been categorized into two broad categories:

Aggregated Exposure – where the area and replacement cost of buildings representing the exposure type are summed at village/city level.

Site Specific Exposure – where every asset in the exposure category is represented by a separate location (Longitude, Latitude) on surface of earth with replacement cost.

The following sub sections describe, how the above-described approach has been applied for these broad exposure categories.

5.1.1.1 Aggregated Exposure

Aggregated exposure at village level has been applied for cyclonic wind, and cyclone-induced coastal flooding due to storm surge, and cyclone induced rainfall flooding. The losses have been estimated only on the area of the built-up cluster that is under the flood depth grids of storm surge and rainfall flooding. Similarly, losses due to cyclonic winds have been estimated over the entire built-up cluster affected with ranges of wind speeds.

The aggregated exposure has been taken for the various structural and infrastructural classes discussed in the exposure section. These classes are hospitals, schools, waste water systems, portable water systems, communication networks, and Religious Places.

5.1.1.2 Site specific exposure

Site-specific exposure is further divided into different types – point location type exposures like Airports, Ports, Electric Power Stations, Bridges, Railway Stations, etc. and line type exposures like roads, railway line, electric transmission lines, pipelines, etc.

5.1.1.2.1 Point Type Exposure

For point type exposure elements the loss computation was done at the point location level based on the hazard intensity estimated at the location for various scenario events.

L(i, j, k) = MDR(j,i,h) * Value_At_Risk(j,k) **Equation 3**

where:

L(i, j, k) = The loss from event 'I' for exposure type 'j' and location 'k'

MDR(j,i,h) = Mean Damage Ration for exposure type 'j' at a hazard intensity 'h' for event i

Value_At_Risk(j,k) = Replacement cost of the exposure type 'j' and location 'k'

5.1.1.2.2 Line Type Exposure

The treatment for line type exposure was different from point type exposure. Since line type exposure elements are spread over a long area so a single hazard value cannot be used to estimate the losses to them. Since a line type exposure element is made of a set of smaller segments, so the loss was estimated at the centroid of every segment. The losses of all the segments were summed up to estimate the loss to the line exposure element. Figure 5-1 shows an example of segments for Railway lines at which losses are estimated.

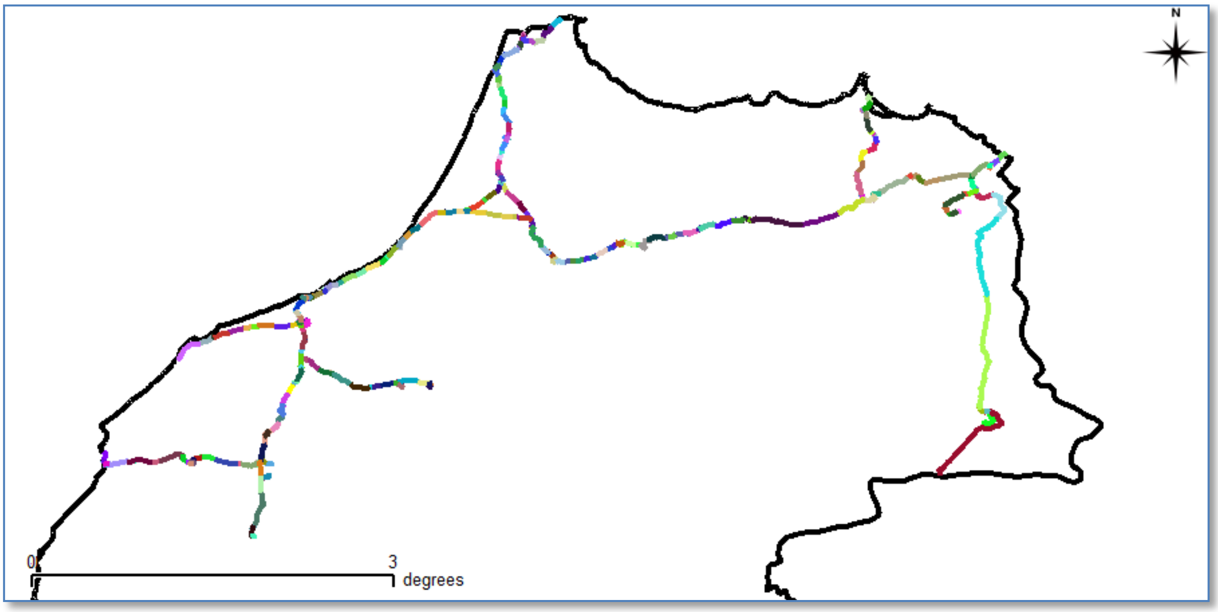

Figure 5-1: Railway lines

The generic equations for loss computation for line type exposure elements takes the following form:

L(i, j, k) = $\sum_{l=0}^{m} MDR(j,i,h) * Value\_At\_Risk(j,k,l)$ **Equation 4**

where:

L(i, j, k) = The loss from event 'I' for exposure type 'j' and line element 'k'

MDR(j,i,h) = Mean Damage Ration for exposure type 'j' at a hazard intensity 'h' for event i

Value_At_Risk(j,k,l) = Replacement cost of the exposure type 'j' and line element 'k' and segment 'l'

The risk metrics (PML) can be used to identify and prioritize the parts of village that are under risk. All the areas and exposure categories that have high PML are automatic choices for mitigation measures.

Following sections illustrate validation process of the losses generated by the risk assessment model and then present the losses estimated for various deterministic scenarios and discuss them in detail due to the three hazards associated with the cyclone. The losses are presented as tables and maps depicting the losses in multiple ways to make it easier to understand the underlying risk.

5.2 Risk Assessment Model Validation

Losses are calibrated and validated against historical events wherever observed loss values are available from wind, storm surge, and cyclone induced rainfall flood impacts. Every cyclone does not result in surge and rainfall induced flooding. Therefore, for validation and calibration, it is important to identify a set of cyclone events that could help validate and calibrate losses due to wind, storm surge and rainfall induced flood individually as well as combined. Keeping this in mind, the 2013-cyclonic storm Phailin was used to validate and calibrate the losses from wind, surge as well as rainfall induced flood as Phailin was associated with strong winds, a decent surge height, and also resulted in rainfall-induced floods. The estimated losses due to cyclonic wind speeds and associated storm surges were validated and calibrated against the most recent 2014-cyclonic storm Hudhud. The estimated losses due to cyclone induced rainfall flooding were validated and calibrated against 2008-deep depression for Odisha; and two historical events, namely, 2000-depression and 2005-cyclonic storm Parr for Andhra Pradesh.

The cyclone induced hazards of wind, storm surge, and flood due to these events were studied in the "Hazard Assessment Report for Andhra Pradesh and Odisha". The details of estimated losses for these historical events are discussed in this section.

5.2.1 LOSS ESTIMATES DUE TO PHAILIN CYCLONE IN ODISHA

The very severe cyclonic storm Phailin crossed Odisha and adjoining north Andhra Pradesh coast near Gopalpur (Odisha) around 2230 hrs IST of 12th October 2013 with a sustained maximum surface wind speed of 200-210 km/h gusting to 220 km/h (IMD Report, 2013). Phailin mainly affected Odisha and coastal Andhra Pradesh. It severely affected many districts of Odisha such as Angul, Balasore, Bhadrak, Bolangir, Cuttak, Ganjapati, Ganjam, Jagatsinghpur, Jajpur, Kandhamal, Kendrapara, Keonjhar, Khurda, Koraput, Mayurbhanj, Nayagarh, and Puri. In addition, three districts, namely, Srikakulam, Vizainagaram, and Visakhapatnam of Andhra Pradesh were also affected due to Phailin. The worst hit was the Ganjam district of Odisha, where the cyclone made landfall. Over 200,000 hectares of agricultural land area was affected having a reported agriculture crops loss INR 1,016.3 crores alone in Ganjam, Puri, and Khorda district (RDNA, 2013[15]). The cyclone reportedly caused damage to about 200,000 houses, as per the state government. Power transmission was also crippled in the district as 40 transmission towers collapsed due to the cyclone's fury. Balasore and Mayurbhanj districts were severely affected by heavy floods. In Balasore alone, 300,000 people were stuck because of the flooding.

In Andhra Pradesh, the damage was less, but still considerable. Coconut plantations across 3,200 hectares in the Srikakulum district were damaged and power supply affected.

[15] RDNA (2013). Rapid Damage and Needs Assessment Report, INDIA Cyclone Phailin in Odisha, October 2013. A report published by the ADB, Govt. of Odisha, and the World Bank, Dec., 2013.

Severity caused by the cyclone Phailin is shown in a few photographs (Figure 5-2). Loss estimates of Phailin associated with wind, and storm surge inundation, and cyclonic rainfall induced flooding are discussed in subsequent sections.

Figure 5-2: Few Damage Photographs associated with Very Severe Cyclonic Storm Phailin (https://www.google.co.in/)

5.2.1.1 Loss estimates due to cyclonic winds

Details of loss estimates due to cyclonic wind associated with Phailin in the study area for residential, commercial and industrial buildings are given in Table 5-1 . It is clear from the table that district Ganjam was most affected in terms of economic losses due to cyclonic winds for residential, commercial, and industrial buildings compared to other districts. Ganjam has highest estimated residential losses of INR 1,676.42 crores followed by Khorda with INR 68.66 crores. However, estimated losses were found moderate for buildings located in Puri and Cuttack districts. In addition, Ganjam and Khordha have the highest estimated commercial losses of INR 291.91 crores and INR 27.15 crores, respectively. The Table also shows that residential and industrial losses contribute higher wind losses as compared to the commercial losses. Residential, Commercial, and Industrial building losses contribute about 63%, 12%, and 25% losses respectively to the combined structural losses.

Table 5-1: Loss Estimates for Cyclonic Winds due to Phailin in Odisha

Sl. No.	Affected Districts	Estimated Losses (INR Crores)			
		Residential	Commercial	Industrial	Combined Losses
1	Baleshwar	-	-	264.10	264.10
2	Bhadrak	-	-	0.01	0.01
3	Cuttack	2.81	0.77	0.59	4.17
4	Ganjam	1,676.42	291.91	141.36	2,109.69
5	Jagatsinghpur	0.88	0.26	0.05	1.19
6	Kendrapara	-	-	0.01	0.01
7	Khordha	68.66	27.15	18.06	113.87
8	Puri	60.8	12.61	300.46	373.87
Grand Total		1,809.57	332.7	724.64	2,866.91

Details of affected districts, villages, households and population are given in Table 5-2. The table shows that Puri was the worst affected district in Odisha by cyclonic winds associated to Phailin with highest affected population, and households. Detailed distribution of vulnerable households in various damage classes is given in Table 5-3.

Table 5-2: Vulnerable villages, households, and population for cyclonic winds due to Phailin in Odisha

Sl. No.	Affected Districts	Number of Affected Villages	Number of Affected Households	Affected Population	Affected Population (%)
1	Ganjam	697	2,80,252	12,54,980	96%
2	Khordha	427	1,84,416	6,97,761	79%
3	Puri	181	3,86,436	13,93,502	79%
Grand Total		1,305	8,51,104	33,46,243	84%

Table 5-3: Vulnerable households in various damage classes for cyclonic winds due to Phailin in Odisha

Affected Districts	Estimated Damaged Households					
	<1%	1-5%	5-25%	25-40%	>40%	Total
Baleshwar	-	-	-	-	-	-
Bhadrak	-	-	-	-	-	-
Cuttack	2,49,374	-	-	-	-	2,49,374
Ganjam	-	17,482	2,08,875	47,934	5,961	2,80,252
Jagatsinghpur	1,79,490	-	-	-	-	1,79,490
Jajpur	-	-	-	-	-	-
Kendrapara	296	-	-	-	-	296
Khordha	1,00,029	49,118	35,151	118	-	1,84,416
Mayurbhanj	-	-	-	-	-	-
Puri	3,42,523	30,485	11,075	2,262	91	3,86,436
Grand Total	8,71,713	97,085	2,55,100	50,314	6,052	12,80,265

Details of the vulnerable infrastructure asset classes, public utilities, and essential facilities due to Phailin are summarized in Table 5-4 and Table 5-5. The associated estimated losses of these vulnerable exposure classes due to Phailin induced strong winds are summarized in Table 5-6. The analysis indicates that schools contribute the highest losses of INR 241.10 crores (42%) followed by electricity lines which contribute INR 129.64 crores (23%) to the total losses of public utilities and infrastructure due to Phailin in Odisha. However, losses for hospitals, bridges, religious places, and railway stations are relatively less.

Cultural heritage conservation helps a community not only protect economically valuable physical assets, but also preserves its practices, history, and environment, and a sense of continuity and identity. Twenty-eight Cultural heritage sites are at likely risk from cyclone (Table 5-4). These are invaluable, so the losses could not be calculated in terms of monetary value, but the impact of hazards on these assets has been considered during risk assessment.

Table 5-4: Affected public utilities and infrastructure for cyclonic winds due to Phailin in Odisha

Affected Districts	Cultural Heritage Sites	Fire Stations	Seaports	Railway Station	Admin HQ	Police Stations
Baleshwar	-	-	-	-	-	-
Bhadrak	-	-	-	-	-	-
Cuttack	5	-		-	-	-
Ganjam	3	4	1	23	12	12
Jagatsinghpur	-	-	-	-	-	-
Jajpur	7	-	-	-	-	-
Kendrapara	1	-		-	-	-
Khordha	2	2		12	3	9
Mayurbhanj	-	-	-	-	-	-
Puri	10	1	-	-	2	4
Grand Total	28	7	1	35	17	25

Table 5-5: Affected essential facilities and religious places for cyclonic winds due to Phailin in Odisha

Affected Districts	Estimated Damaged Schools					Estimated Damaged Hospitals				Estimated Damaged Religious Places			
	<1%	1%-5%	5%-25%	25%-40%	>40%	<1%	1%-5%	5%-25%	>25%	<1%	1%-5%	5%-25%	>25%
Baleshwar	-	-	-	-	-	-	-	-	-	2,334	-	-	-
Bhadrak	-	-	-	-	-	-	-	-	-	1,082	-	-	-
Cuttack	1,658	-	-	-	-	798	-	-	-	885	-	-	-
Ganjam	-	321	1,662	102	89	-	49	454	-	-	220	461	-
Jagatsinghpur	2,272	-	-	-	-	214	-	-	-	1,227	-	-	-
Jajpur	-	-	-	-	-	-	-	-	-	970	-	-	-

Affected Districts	Estimated Damaged Schools					Estimated Damaged Hospitals				Estimated Damaged Religious Places			
	<1%	1%-5%	5%-25%	25%-40%	>40%	<1%	1%-5%	5%-25%	>25%	<1%	1%-5%	5%-25%	>25%
Kendrapara	2	-	-	-	-	-	-	-	-	1,417	-	-	-
Khordha	1,255	554	33	1	-	575	628	-	-	501	304	-	-
Mayurbhanj	-	-	-	-	-	-	-	-	-	362	-	-	-
Puri	3,208	189	67	4	1	480	38	9	-	1,508	69	29	-
Grand Total	8,395	1,064	1,762	107	90	2,067	715	463	0	10,286	593	490	0

Table 5-6: Losses for affected public utilities, infrastructure and essential facilities and religious places for cyclonic winds due to Phailin in Odisha

Affected Districts	Losses (INR Crores)															
	Schools	Hospitals	Police Stations	Bridges	Admin HQ	Electricity Lines	Fire Stations	Sea Ports	Railway lines	Railway Stations	Roads	Religious Places	Communication	Telecom Towers	Potable Water Systems	Waste Water Systems
Baleshwar	-	-	-	0.01	-	-	-	-	-	-	-	0.01	-	0.03	-	-
Bhadrak	-	-	-	-	-	-	-	-	-	-	-	0.01	-	0.02	-	-
Cuttack	0.31	0.14	-	0.06	-	0.10	-	-	-	0.02	-	0.03	-	0.03	-	-
Ganjam	206.70	19.91	0.65	10.88	1.38	114.77	0.42	97.91	2.06	6.71	1.43	8.76	0.23	24.88	0.65	0.30
Jagatsingh	0.25	0.01	-	0.03	-	0.05	-	0.15	-	-	-	0.02	-	0.04	-	-
Jajpur	-	-	-	0.01	-	-	-	-	-	0.01	-	0.01	-	0.02	-	-
Kendrapar	-	-	-	0.01	-	-	-	-	-	-	-	0.02	-	0.03	-	-
Khordha	25.02	7.38	0.09	0.07	0.09	10.01	0.03	-	0.23	0.69	0.15	1.69	0.02	3.88	0.01	0.02
Mayurbhan	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	-	-
Puri	8.82	1.05	0.03	1.33	0.03	4.71	0.05	-	0.02	0.14	0.20	0.97	0.01	3.71	0.06	0.01
Grand Total	241.10	28.49	0.77	12.40	1.50	129.64	0.50	98.06	2.31	7.57	1.78	11.52	0.26	32.64	0.72	0.33

The residential, industrial, and commercial building losses at village level due to the 2013-Phailin cyclone are shown in Figure 5-3, Figure 5-4, and Figure 5-5, respectively.

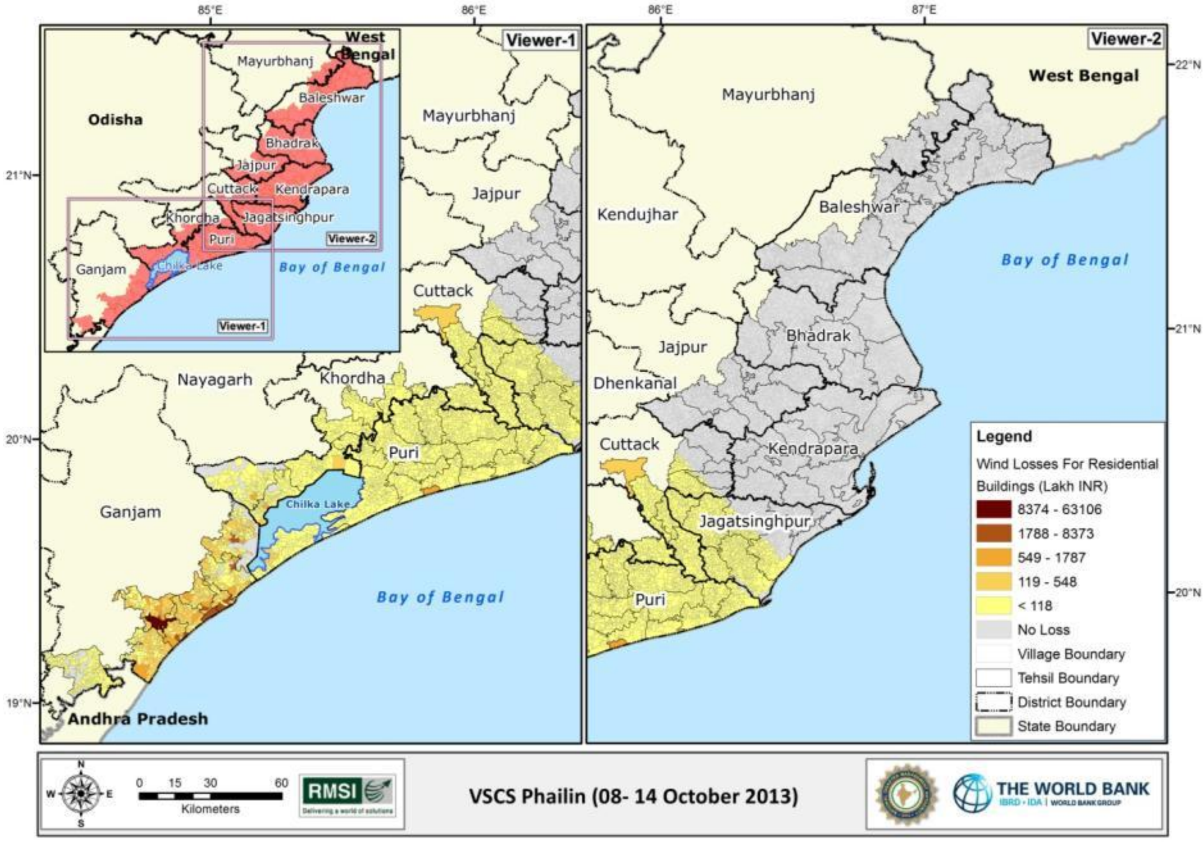

Figure 5-3: Estimated losses for cyclonic winds due to Phailin for residential buildings

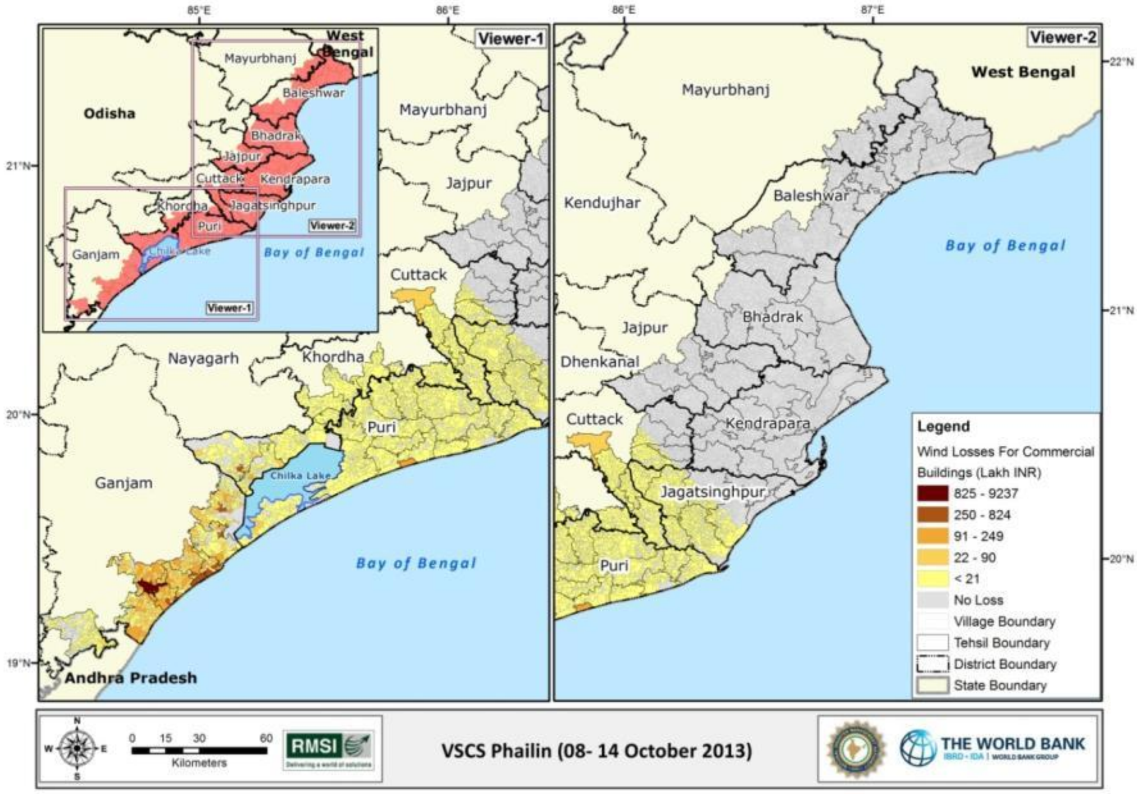

Figure 5-4: Estimated losses for cyclonic winds due to Phailin for commercial buildings

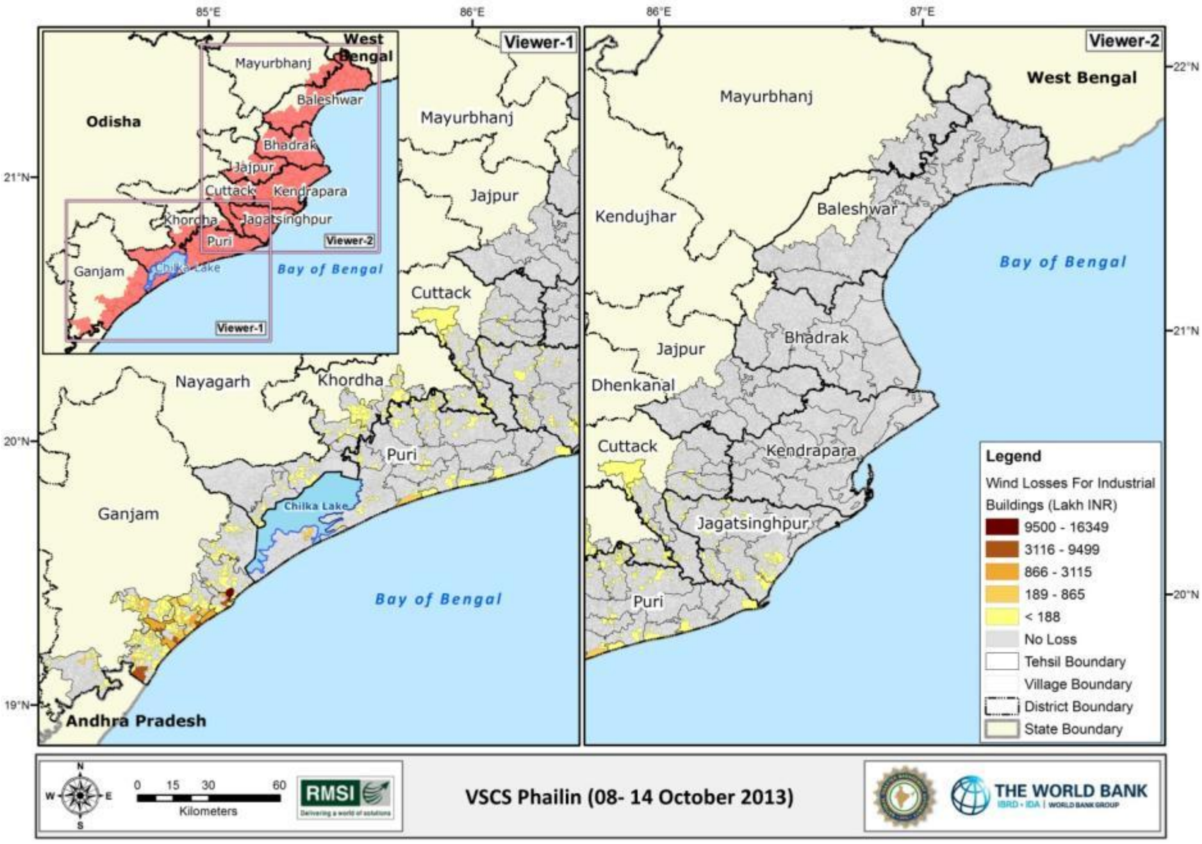

Figure 5-5: Estimated losses for cyclonic winds due to Phailin for industrial buildings

5.2.1.2 Loss estimates due to storm surge

Details of loss estimates due to storm surge inundation for Phailin in the study area for residential, commercial, and industrial buildings are given in Table 5-7. It is clear from the table that Baleshwar district was most affected in terms of economic losses due to storm surge for residential, commercial, and industrial buildings compared to other districts. The Table also shows that industrial building losses contributed higher losses as compared to the residential and commercial building losses. Industrial building losses contribute about 97% losses to the combined structural losses.

Table 5-7: Loss estimates for storm surge due to Phailin in Odisha

Sl. No.	Affected Districts	Estimated Losses (INR Crores)			
		Residential	Commercial	Industrial	Combined Losses
1	Baleshwar	0.07	0.02	16.63	16.72
2	Bhadrak	0.27	0.02	-	0.29
3	Ganjam	0.11	-	-	0.11
4	Jagatsinghpur	0.03	-	0.01	0.04
5	Kendrapara	0.02	0.01	-	0.03
6	Puri	0.02	-	-	0.02
Grand Total		0.52	0.05	16.64	17.21

Details of affected districts, number of affected villages, households, and population are given in the Table 5-8. The table shows that Bhadrak was the worst affected district in Odisha by storm surge inundation associated to Phailin with the highest affected population, households, and villages of about 959, 186, and 68 respectively. However, losses were found relatively low for Jagatsinghpur and Kendrapara. Overall analysis of the losses indicates that Odisha was less affected due to storm surge inundation compared to losses due to cyclonic winds.

Table 5-8: Vulnerable villages, households and population for storm surge due to Phailin in Odisha

Sl. No.	Affected Districts	Number of Affected Villages	Number of Affected Households	Affected Population	Affected Population (%)
1	Baleshwar	49	69	304	0.01%
2	Bhadrak	68	186	959	0.07%
3	Ganjam	36	50	155	0.01%
4	Jagatsinghpur	49	190	831	0.07%
5	Kendrapara	134	120	520	0.04%
6	Puri	69	5	23	0.00%
Grand Total		405	620	2,792	0.03%

Details of vulnerable infrastructure asset classes, public utilities and essential facilities due to Phailin are summarized in the Table 5-9 and Table 5-10. The associated estimated losses of these vulnerable exposure classes for storm surge inundation due to Phailin are given in Table 5-11. The table shows that religious places contribute the highest losses of INR 2.2

crores (42%) followed by hospitals which contribute INR 1.74 crores (33%) to the total losses of public utilities and infrastructure due to Phailin in Odisha.

Table 5-9: Affected public utilities and infrastructure for storm surge due to Phailin in Odisha

Affected Districts	Schools	Hospitals	Seaports	Bridges	Religious Places	Police Stations
Baleshwar	-	-	-	-	-	-
Bhadrak	-	-	-	1	-	-
Cuttack	-	-	-	-	-	-
Ganjam	34	4	1	1	365	-
Jagatsinghpur	-	-	1	1	-	-
Kendrapara	-	-	-	1	-	1
Khordha	-	-	-	-	-	-
Puri	8	1	-	-	102	-
Grand Total	42	5	2	4	467	1

Table 5-10: Vulnerable essential facilities and religious places for storm surge due to Phailin in Odisha

Affected Districts	Estimated Damaged Schools			Estimated Damaged Hospitals			Estimated Damaged Cyclone Shelters			Estimated Damaged Religious Places			
	<1%	1%-5%	>5%	<1%	1%-5%	>5%	<1%	1%-5%	>5%	<1%	1%-5%	5%-25%	>25%
Baleshwar	50	-	-	2	-	-	-	-	-	635	-	-	-
Bhadrak	44	-	-	11	-	-	-	-	-	492	-	-	-
Cuttack		-	-		-	-	-	-	-		-	-	-
Ganjam		34	-		4	-	-	-	-		365	-	-
Jagatsinghpur	27	-	-	2	-	-	-	-	-	774	-	-	-
Jajpur		-	-		-	-	-	-	-		-	-	-
Kendrapara	24	-	-	3	-	-	-	-	-	525	-	-	-
Khordha		-	-		-	-	-	-	-		-	-	-
Mayurbhanj		-	-		-	-	-	-	-		-	-	-
Puri	51	8	-	9	1	-	-	-	-	1,069	102	-	-
Grand Total	196	42	0	27	5	0	0	0	0	3,495	467	0	0

Table 5-11: Losses for affected public utilities and infrastructure for storm surge due to Phailin in Odisha

Affected Districts	Losses (INR Crores)								
	Schools	Hospitals	Religious Places	Police Stations	Seaports	Bridges	Communication	Potable Waters	Waste waters
Baleshwar	1.87	0.02	0.30	-	-	-	0.04	-	-
Bhadrak	1.75	0.12	0.31	-	-	0.01	0.03	-	0.01
Cuttack	-	0.01	-	-	-	-	-	-	-
Ganjam	13.07	0.35	0.46	-	0.45	0.02	0.06	0.03	0.02
Jagatsinghpur	3.49	0.11	0.27	-	0.39	0.03	0.02	0.01	0.02
Kendrapara	1.45	0.04	0.26	0.001	-	0.01	0.02	-	0.01
Khordha	-	0.01	-	-	-	-	-	-	-
Puri	11.46	1.08	0.60	-	-	-	0.06	0.01	0.02
Grand Total	33.11	1.74	2.20	0.001	0.84	0.07	0.23	0.05	0.08

The residential, industrial, and commercial building losses at village-level due storm surge associated with the Phailin cyclone are shown in Figure 5-6, Figure 5-7, and Figure 5-8, respectively.

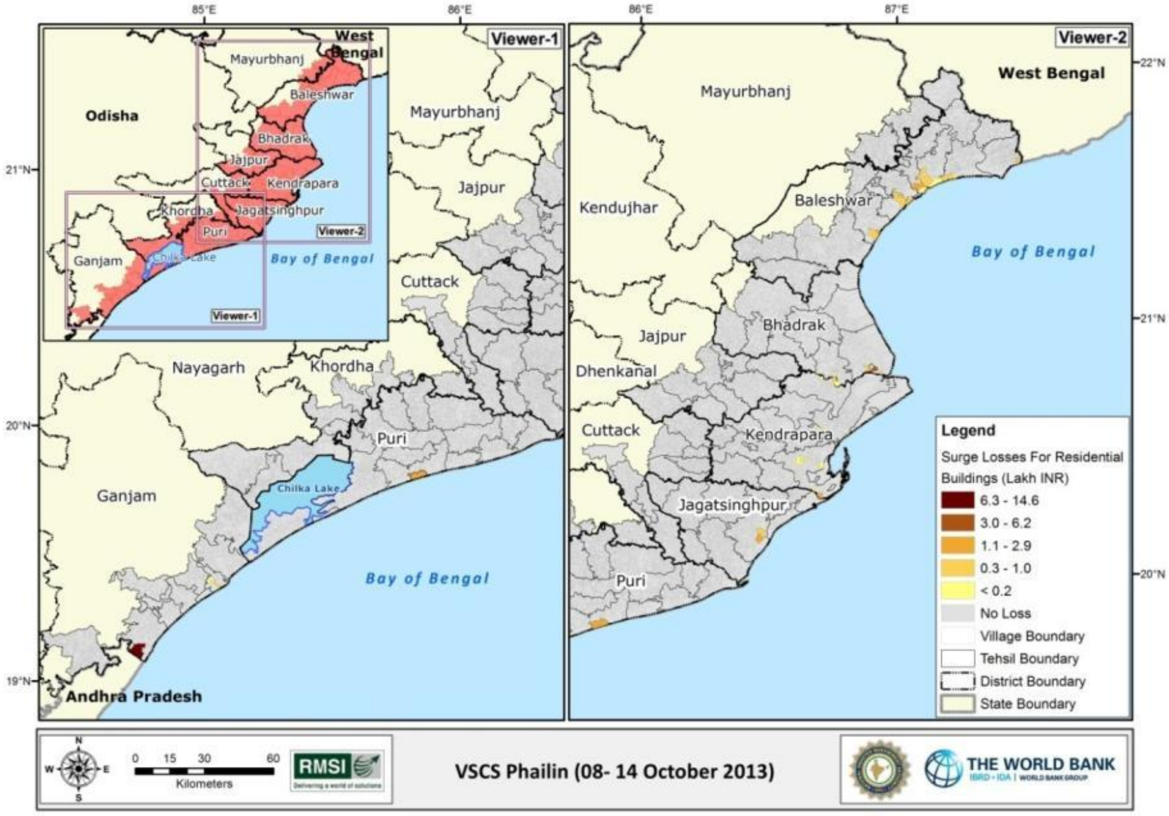

Figure 5-6: Estimated losses for storm surge due to Phailin for residential buildings

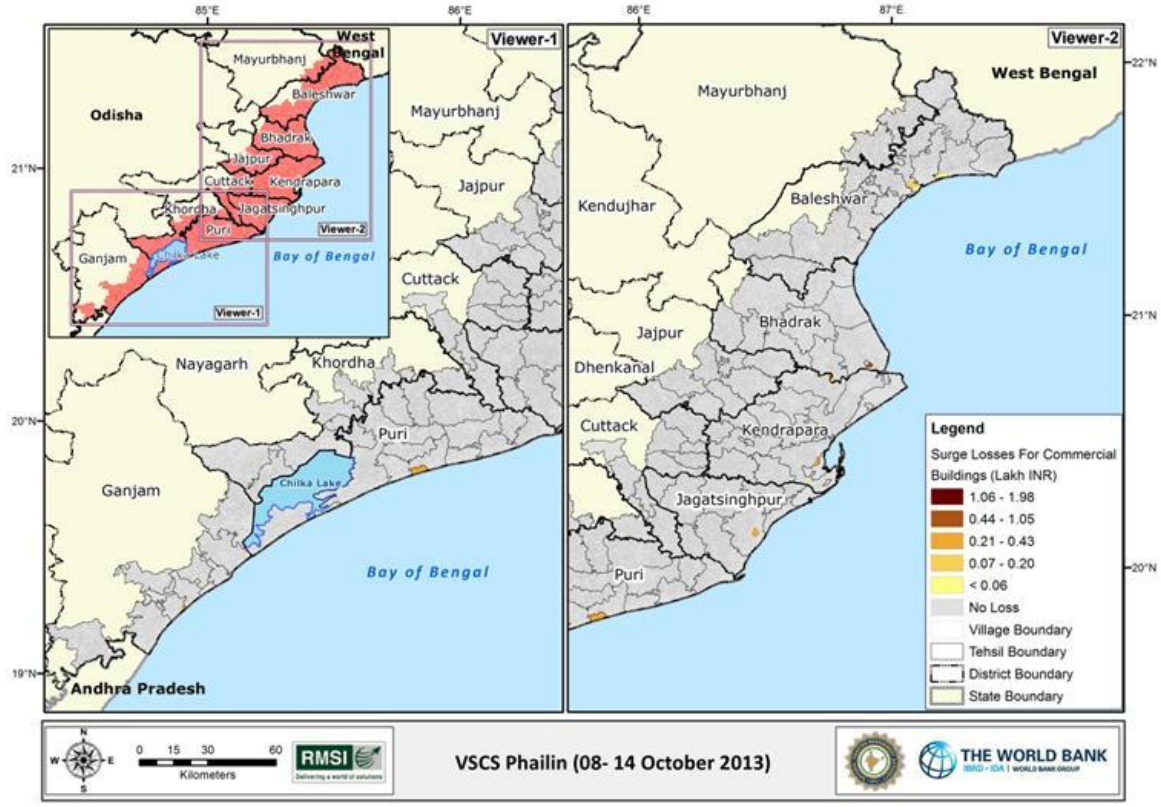

Figure 5-7: Estimated losses for storm surge due to Phailin for commercial buildings

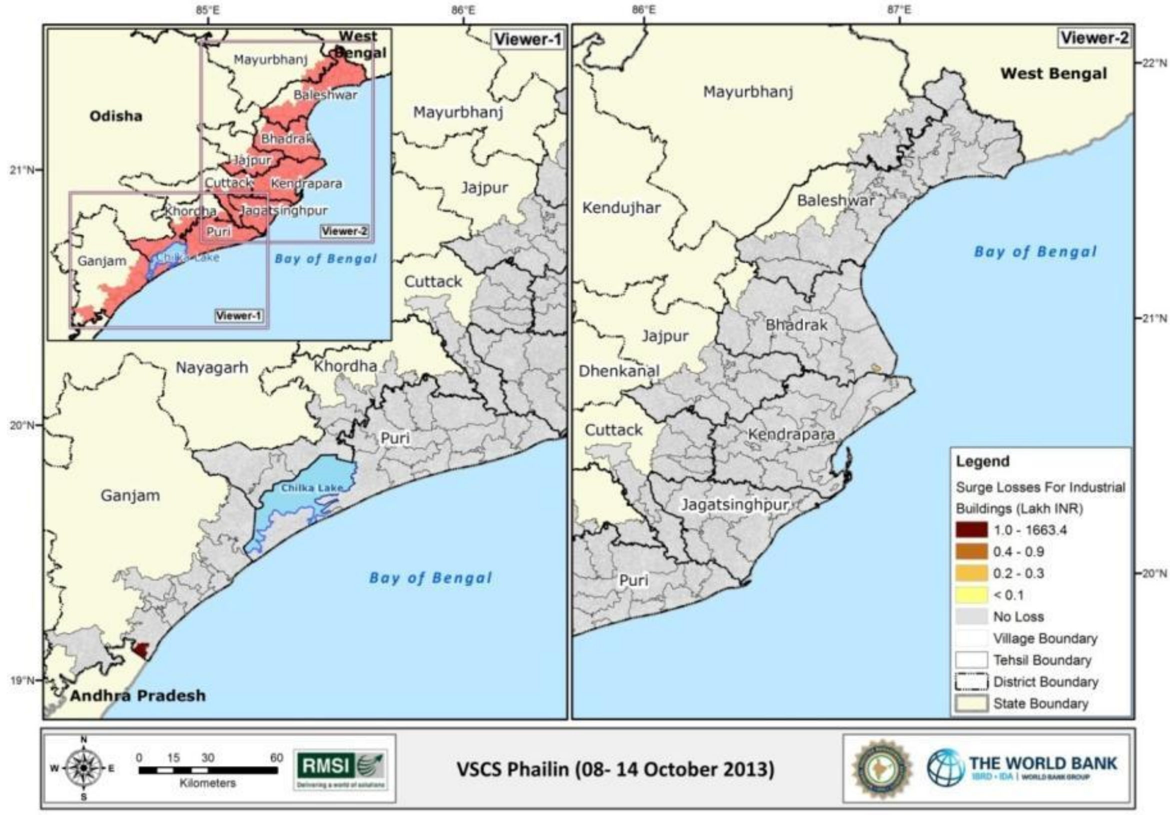

Figure 5-8: Estimated losses for storm surge due to Phailin for industrial buildings

5.2.1.3 Loss estimates due to cyclone induced rainfall flood

Details of loss estimates due to cyclone induced rainfall flooding for Phailin in the study area for Residential, Commercial, and Industrial building are given in Table 5-12. The table shows that Jagatsinghpur has the highest estimated residential losses of INR 30.29 crores followed by Cuttack with INR 18.83 crores. Kendrapara and Cuttack have the highest estimated commercial losses of INR 8.68 and 5.17 crores, respectively. Table 5-12 also shows that residential and industrial building losses contribute higher flood losses as compared to the commercial building losses. Residential, Commercial, and Industrial building losses contribute about 44%, 16%, and 40% losses respectively to the combined structural losses.

Table 5-12: Loss estimates of cyclone induced rainfall flood due to Phailin in Odisha

Sl. No.	Affected Districts	Estimated Losses (INR crores)			
		Residential	Commercial	Industrial	Combined Losses
1	Baleshwar	8.02	3.30	9.29	20.62
2	Bhadrak	6.68	2.81	4.67	14.16
3	Cuttack	18.83	5.17	3.47	27.47
4	Ganjam	2.32	0.34	6.33	8.99
5	Jagatsinghpur	30.29	7.07	37.30	74.66
6	Jajpur	12.38	3.46	0.29	16.13
7	Kendrapara	7.43	8.68	21.29	37.40
8	Khordha	1.41	0.19	0.06	1.66
9	Mayurbhanj	0.04	0.02	0.09	0.15
10	Puri	4.67	0.76	0.93	6.36
Grand Total		92.07	31.80	83.72	207.60

Details of the affected districts, affected number of villages, households, and population are given in the Table 5-13. Detailed distribution of vulnerable households and population in various damage classes are given in Table 5-14 and Table 5-15 respectively. The table shows that Kendrapara was the worst affected district in Odisha by cyclone induced rainfall flooding due to Phailin with highest affected population, affected villages, and affected households.

Table 5-13: Vulnerable villages, households, and population for cyclone induced rainfall flood due to Phailin in Odisha

Sl. No.	Affected Districts	Affected Villages	Affected Households	Affected Population	Affected Population (%)
1	Baleshwar	459	6,689	29,962	10%
2	Bhadrak	357	10,198	52,661	17%
3	Cuttack	640	27,886	122,719	14%
4	Ganjam	33	1,991	9,354	30%
5	Jagatsinghpur	888	37,936	165,388	18%
6	Jajpur	664	20,872	92,335	23%
7	Kendrapara	1,151	47,650	208,231	20%
8	Khordha	58	1,447	6,986	8%
9	Mayurbhanj	8	53	228	5%
10	Puri	281	8,277	37,556	8%
Grand Total		4,539	162,999	725,420	16%

Table 5-14: Vulnerable households in various damage classes for cyclone induced rainfall flood due to Phailin in Odisha

District	Household Damaged					
	<1%	1-5%	5-10%	10-20%	>20%	Total
Baleshwar	36	916	2,225	3,469	43	6,689
Bhadrak	325	1,909	4,634	3,326	4	10,198
Cuttack	586	6,560	16,166	4,251	323	27,886
Ganjam	12	366	885	728	-	1,991
Jagatsinghpur	1,207	9,803	19,176	7,649	101	37,936
Jajpur	160	5,895	11,719	2,970	128	20,872
Kendrapara	1,078	8,207	26,972	11,151	242	47,650
Khordha	56	400	949	42	-	1,447
Mayurbhanj	31	2	5	1	14	53
Puri	579	4,191	3,506	-	1	8,277
Grand Total	4,070	38,249	86,237	33,587	856	162,999

Table 5-15: Vulnerable population in various damage classes for cyclone induced rainfall flood due to Phailin in Odisha

District	Population Affected					
	<1%	1-5%	5-10%	10-20%	>20%	Total
Baleshwar	169	4,109	10,013	15,455	216	29,962
Bhadrak	1,682	9,802	24,025	17,130	22	52,661
Cuttack	2,578	28,854	71,198	18,658	1,431	122,719
Ganjam	58	1,640	4,193	3,463	-	9,354
Jagatsinghpur	5,314	42,729	83,782	33,118	445	165,388
Jajpur	722	25,621	52,178	13,248	566	92,335
Kendrapara	4,679	35,990	118,025	48,478	1,059	208,231
Khordha	257	1,916	4,613	200	-	6,986
Mayurbhanj	133	9	24	5	57	228
Puri	2,613	18,894	16,044	-	5	37,556
Grand Total	18,205	169,564	384,095	149,755	3,801	725,420

Details of the vulnerable infrastructure asset classes, public utilities, and essential facilities due to Phailin are summarized in Table 5-16 and

Table 5-17. The associated estimated losses of these vulnerable exposure classes due to Phailin are given in Figure 5-17. Roads contribute the highest losses of INR 145.03 crores (45%) followed by schools which contribute INR 74.14 crores (23%) to the total losses of public utilities, infrastructure, and essential facilities due to Phailin in Odisha.

Table 5-16: Vulnerable public utilities and infrastructure for cyclone induced rainfall flooding due to Phailin in Odisha

Affected Districts	Bridges	Railway Stations	Seaports	Admin HQ	Fire Stations	Police Stations
Baleshwar	51	-	-	2	1	-
Bhadrak	17	-	-	2	-	-
Cuttack	78	-	-	2	1	-
Ganjam	12	-	-	1	-	-
Jagatsinghpur	63	6	1	1	-	1
Jajpur	32	-	-	2	-	2
Kendrapara	49	-	-	5	1	3
Khordha		-	-	-	-	-
Mayurbhanj		-	-	-	-	-
Puri	20	-	-	-	-	-
Grand Total	322	6	1	15	3	6

Table 5-17: Vulnerable essential facilities and religious places for cyclone induced rainfall flooding due to Phailin in Odisha

Affected Districts	Schools Damaged			Hospitals Damaged			Cyclone Shelters Damaged			Religious Places Damaged		
	<1 %	1%- 5%	>5%	<1 %	1%-5%	>5%	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%
Baleshwar	164	641	166	11	65	3	-	2	-	-	272	68
Bhadrak	207	552	20	28	62	6	-	1	-	-	167	7
Cuttack	170	546	238	54	172	141	-	-	-	-	251	37
Ganjam	22	62	2	3	11	-	-	-	-	-	24	2
Jagatsinghpur	350	577	61	44	78	8	-	1	-	-	265	22
Jajpur	189	925	46	28	100	3	-	3	1	-	289	21
Kendrapara	320	1,375	100	35	148	14	-	-	-	-	459	51
Khordha	42	18	-	1	1	-	-	-	-	-	16	-
Mayurbhanj	6	10	5	-	1	-	-	-	-	-	12	4
Puri	215	61	14	27	13	3	-	-	-	-	193	7
Grand Total	1,685	4,767	652	231	651	178	0	7	1	0	1,948	219

Table 5-18: Losses for affected public utilities, infrastructure and essential facilities for cyclone induced rainfall flooding due to Phailin in Odisha

Affected Districts	Losses (INR crores)													
	Schools	Hospitals	Bridges	Electricity Lines	Oil and Gas	Railway Lines	Railway Stations	Roads	Seaports	Religious Places	Admin Headquarter	Cyclone Shelters	Fire Stations	Police Stations
Baleshwar	10.54	0.33	9.71	0.07	1.03	0.85	-	23.95	-	0.92	0.08	0.02	0.01	-
Bhadrak	5.43	0.37	0.56	0.04	0.68	-	-	13.35	-	0.83	0.07	0.05	0	0
Cuttack	21.67	8.46	21.17	0.05	-	4	-	15.99	-	1.6	0.07	-	0.02	-
Ganjam	0.49	0.09	2.01	0.02	-	1.02	-	1.69	-	0.06	0.04	0	-	-
Jagatsinghpur	10.71	0.74	6.37	0.05	0.81	11.6	0.1	22.56	8.86	1.03	0.02	0.02	-	0.01
Jajpur	9.61	0.38	7	0.07	-	-	-	16.35	-	1.17	0.13	0.08	-	0.01
Kendrapara	14.3	0.45	8.65	0.15	1.66	-	-	46.03	-	1.69	0.14	-	0.02	0.02
Khordha	0.25	0.01	-	-	-	-	-	0.67	-	0.07	-	-	-	-
Mayurbhanj	0.19	-	-	-	-	-	-	0.31	-	0.01	-	-	-	-
Puri	0.95	0.12	0.05	0.01	-	0.24	-	4.13	-	0.78	-	-	-	-
Grand Total	74.14	10.95	55.52	0.46	4.18	17.71	0.1	145.03	8.86	8.16	0.55	0.17	0.05	0.04

The residential, commercial and industrial buildings losses at village-level due to Phailin cyclone are shown in Figure 5-9, Figure 5-10, and Figure 5-11 respectively.

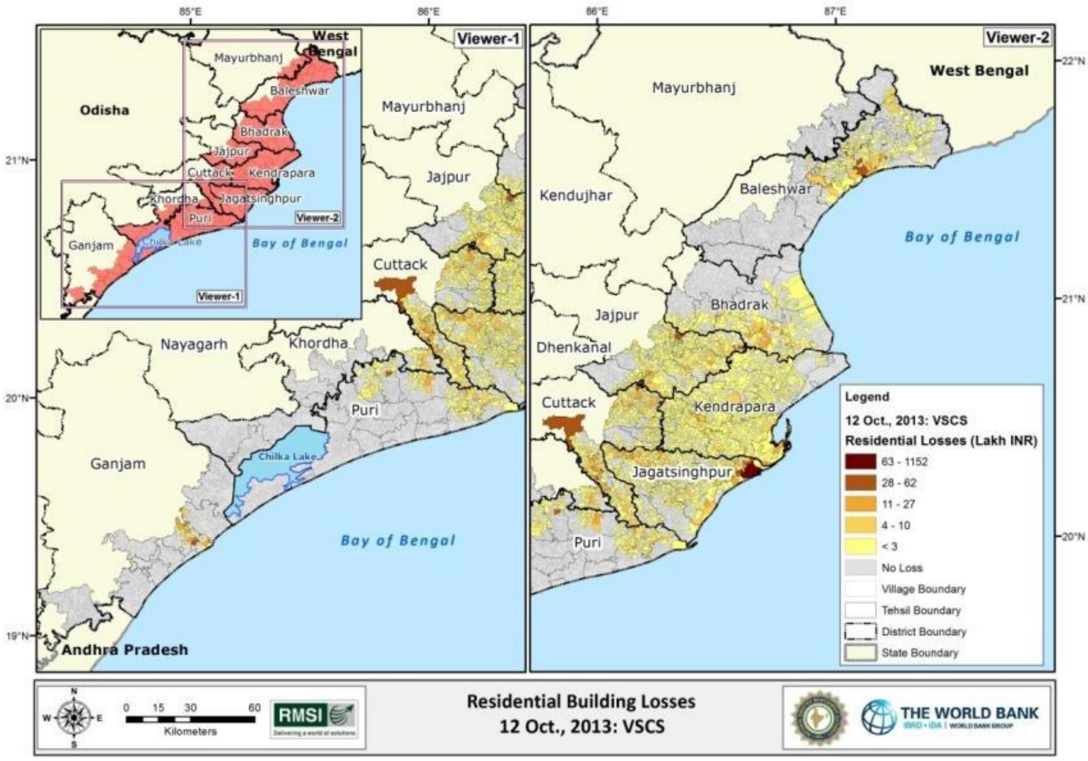

Figure 5-9: Estimated losses for cyclone induced rainfall flood due to Phailin for Residential Buildings

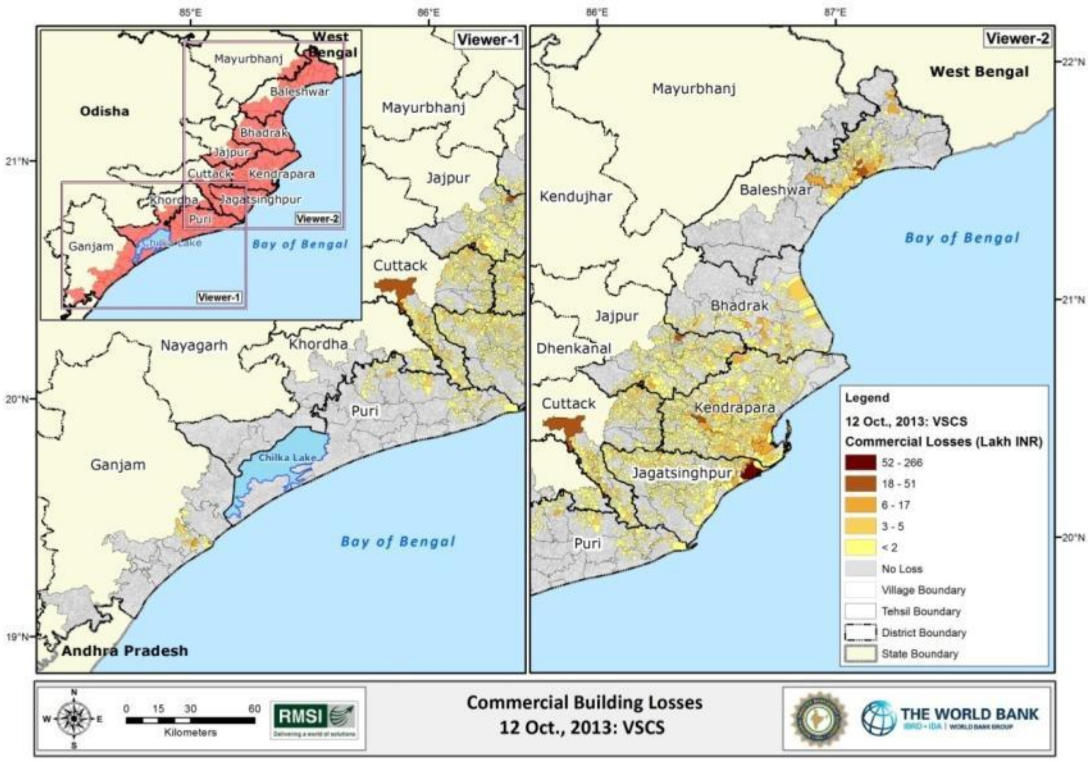

Figure 5-10: Estimated losses for cyclone induced rainfall flood due to Phailin for Commercial Buildings

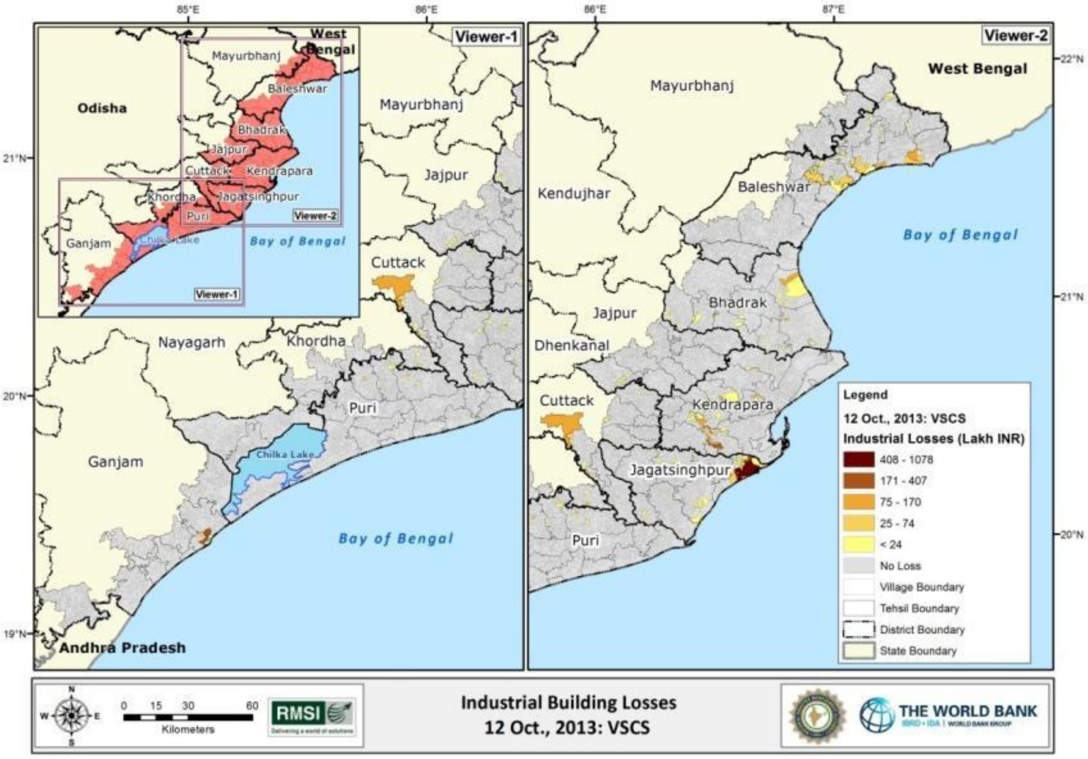

Figure 5-11: Estimated losses for cyclone induced rainfall flood due to Phailin for Industrial Buildings

5.2.1.4 Validation of modeled losses with the reported crop losses due to Phailin cyclone

We also compared Phailin cyclone induced rainfall reported crop production losses with the modeled crop production losses. It is to be noted that Phailin cyclone reported crop production losses are given in terms of monetary value not in terms of crop production. Hence, first we estimated the crop production losses for the two major crops (rice and green gram) and then multiplied them with the 2013 market price of the respective crops. Subsequently, all crop losses were aggregated together for all three affected districts (i.e., Ganjam, Puri, and Khordha) (Table 5-19). Further, comparative results show that modeled estimated crop production loss is less than about 26-27% to the reported crop production loss in terms of monetary value, which is a fairly good estimation in the context of so many approximations involved in this estimation.

Table 5-19: Estimated crop production loss due to Phailin cyclone

District	Crop	Production loss (tons)	Market Price (INR/ton)	Loss (Million INR)
Ganjam	Rice	1,13,720	28,191	3,206
	Green gram	485	46,000	22
Puri	Rice	92,219	28,191	2,600
	Green gram	107	46,000	5
Khorda	Rice	57,554	28,191	1,623
	Green gram	218	46,000	10
Total modeled loss in three districts (Million INR)				7,465
Total reported loss in three districts (Million INR)				10,163
Variation in modeled and reported loss				-27%

In general, there is a good match in the numbers of damaged buildings and infrastructural elements (despite difference in study area extent in reported districts). However, modeled loss estimates have large variations from the RDNA (2013) report as losses reported in the RDNA report are based on simplified assumptions. For example, for damaged houses, reconstruction cost is taken as INR 2.8 lakhs and INR 0.70 lakhs, respectively for urban and rural houses that are fully/severely damaged, respectively. This provides much lower estimates of replacement/reconstruction costs in RDNA estimates than the modeled losses of residential houses. However, for most of the other structures, modeled losses are less than the reported RDNA (2013) estimates, as the study area in the present study is much lower than that used in RDNA estimates.

5.2.1.5 Composite Loss Validation for cyclone Phailin

As stated above, very severe cyclonic storm Phailin was very devastating in terms of economic losses due to the combined impact of associated hazards namely cyclonic winds, storm surge inundation and cyclone induced rainfall flood. The combined losses due to Phailin for all three hazards are compared with reported losses available from various sources. The total losses are calculated using the equation given below.

$$\text{Total Loss} = \sqrt{(\text{Loss due to wind})^2 + (\text{Loss due to surge})^2 + (\text{Loss due to flood})^2}$$

In this study, the losses are estimated for the districts up to 10-m elevation from coastline (study area). However, the reported losses from various available sources for 2013-Phailin cyclone have covered the entire affected area (RDNA, 2013). Hence, considering this, a variation in losses has been observed when estimated losses are compared with reported losses for the event.

The estimated losses presented here are the combined impact of winds, associated surges, and cyclone induced rainfall floods on exposed assets in the study area. The losses have been estimated for ten coastal districts of Odisha, which are partially located up to 10-m elevation from coastline. The comparisons between estimated and reported losses have been made from various available sources (Table 5-20 to Table 5-22). These tables suggest that estimated losses are on the lower side, which may be attributed to the limited study area considered, that do not include the losses for the affected exposure located above 10 m elevation. In addition, the strong gale winds severely impacted Odisha and the adjoining districts of north Andhra Pradesh. The calculated loss statistics are given below.

Table 5-20: Loss validation for affected districts and population due to Phailin Cyclone

Exposure Type	Estimated	Reported
District Affected	3	18
Villages Affected	4,539	18374 (18 districts)
Population Affected	33,46,243	2,303,369 (3 districts)

Table 5-21: Loss validation for affected buildings due to Phailin Cyclone

Affected Districts	Losses (INR Crore)					
	Residential		Commercial		Industrial	
	Estimated	Reported	Estimated	Reported	Estimated	Reported
Ganjam	1,676	686	292	-	1,375	-
Khordha	69	315	27	-	6	-
Puri	61	120	13	-	62	-
Total	1,806	1,121	362	-	1,519	-

Table 5-22: Loss validation for affected public utilities due to Phailin Cyclone

Affected Districts	Affected Schools		School Losses (INR crores)		Affected Hospitals		Hospital Losses (INR crores)	
	Reported	Estimated	Reported	Estimated	Reported	Estimated	Reported	Estimated
Ganjam	1751	1,855	83.6	207.11	155	151	9.2	6.63
Puri	368	390	18.5	11.50	13	11.4	0.9	1.09
Khordha	418	591	15.6	0.25	26	28.7	1.36	1.00
Total	2,537	2,836	118	219	194	191	11.46	8.72

5.2.2 Loss Estimates due to Deep Depression (2008) in Odisha

The rainstorm of 16-18 September 2008 was caused by a low-pressure area that formed over North Bay of Bengal on 15 September, which later concentrated and intensified into a deep depression and crossed the Odisha coast near Chandbali on 17th September. The event caused very heavy rainfall over entire Odisha and a few adjoining areas of Chhattisgarh and Gangetic West Bengal during 16-18 September; though it was not accompanied by any damaging winds or surge. So all the impact from the event was primarily due to the cyclonic rainfall induced flooding.

Several districts were seriously affected, including Angul, Bargarh, Bhadrak, Bolangir, Boudh, Cuttack, Gajapati, Jagatsinghpur, Jajpur, Kalahandi, Kendrapara, Keonjhar, Khurda, Nayagarh, Puri, Rayagada, Sambalpur, Nuapara and Subarnapur. In total, the 21 districts were affected. The flood caused extensive damage to natural resources, physical infrastructure, and livelihood. It had an adverse impact on the social fabric of the flood-affected areas.

The severity of the flood caused by the 2008 event is shown in the few photographs in Figure 5-12.

Figure 5-12: Flood damage photographs associated with 2008 flooding in Odisha

Details of loss estimates due to cyclone induced rainfall flooding caused by the 2008 deep depression in the study area for Residential, Commercial and Industrial buildings are given in Table 5-23. The table shows that the highest estimated residential building losses of INR 91 crores occurred in Jagatsinghpur and of INR 59.81 crores in Cuttack. The highest commercial building losses of INR 24.07 crores and 13.54 crores were estimated for Jajpur and Jagatsinghpur respectively. The table also shows that residential and industrial building losses contributed higher flood losses as compared to commercial building losses.

Residential, Commercial, and Industrial building losses contribute about 55%, 15%, and 30% losses respectively to the combined structural losses.

Table 5-23: Loss estimates of cyclone induced rainfall flood due to 2008-Deep Depression in Odisha

Sl. No.	Affected Districts	Estimated Losses (INR crores)			
		Residential	Commercial	Industrial	Combined Losses
1	Baleshwar	8.92	1.32	4.28	14.53
2	Bhadrak	13.26	0.33	6.39	19.97
3	Cuttack	59.81	10.58	8.56	78.95
4	Jagatsinghpur	91.00	13.54	1.91	106.45
5	Jajpur	14.27	24.07	66.27	104.60
6	Kendrapara	17.99	1.08	0.34	19.42
7	Khordha	4.67	12.07	37.77	54.51
8	Mayurbhanj	0.23	0.53	0.15	0.91
9	Puri	24.43	0.01	0.02	24.46
10	Ganjam	1.67	3.12	5.39	10.18
Grand Total		**236.25**	**66.64**	**131.08**	**433.97**

Details of the affected districts, number of villages, affected households, and population are given in the Table 5-24. Detailed distribution of vulnerable households and population in various damage classes are given in Table 5-25 and Table 5-26 respectively. The table shows that Kendrapara was the worst affected district in Odisha by cyclone induced rainfall flooding due to the 2008 deep depression with highest affected population, affected villages, and affected households.

Table 5-24: Vulnerable villages, households, and population due to 2008-Deep Depression in Odisha

Sl. No.	Affected Districts	Affected Villages	Affected Households	Affected Population	Affected Population (%)
1	Baleshwar	465	9,735	43,430	18%
2	Bhadrak	463	20,922	107,810	66%
3	Cuttack	825	67,421	300,304	67%
4	Ganjam	30	1,590	7,484	20%
5	Jagatsinghpur	1,158	97,027	423,795	80%
6	Jajpur	678	24,022	105,566	29%
7	Kendrapara	1,315	103,091	448,050	65%
8	Khordha	87	3,881	18,586	37%
9	Mayurbhanj	10	145	611	20%
10	Puri	761	29,576	133,832	75%
Grand Total		5,792	357,410	1,589,468	59%

Table 5-25: Vulnerable households in various damage classes for cyclone induced rainfall flood due to 2008-Deep Depression in Odisha

District	Household Damaged					
	<1%	1-5%	5-10%	10-20%	>20%	Total

District	Household Damaged					
	<1%	1-5%	5-10%	10-20%	>20%	Total
Baleshwar	153	1,355	5,592	2,537	98	9,735
Bhadrak	548	4,861	9,986	5,463	64	20,922
Cuttack	1,513	11,315	38,334	15,907	352	67,421
Ganjam	45	276	1,238	31	-	1,590
Jagatsinghpur	1,020	17,880	46,846	30,529	752	97,027
Jajpur	731	5,398	13,254	4,510	129	24,022
Kendrapara	5,912	14,173	48,450	34,224	332	103,091
Khordha	147	1,152	2,275	307	-	3,881
Mayurbhanj		17	31	97	-	145
Puri	445	8,013	17,693	3,424	1	29,576
Grand Total	10,514	64,440	183,699	97,029	1,728	357,410

Table 5-26: Vulnerable population in various damage classes for cyclone induced rainfall flood due to 2008-Deep Depression in Odisha

District	Population Affected					
	<1%	1-5%	5-10%	10-20%	>20%	Total
Baleshwar	699	6,067	24,883	11,292	489	43,430
Bhadrak	2,820	25,035	51,459	28,163	333	107,810
Cuttack	6,684	50,608	171,088	70,353	1,571	300,304
Ganjam	219	1,249	5,866	150	-	7,484
Jagatsinghpur	4,477	78,382	204,646	132,865	3,425	423,795
Jajpur	3,089	23,000	58,874	20,034	569	105,566
Kendrapara	24,185	62,083	210,922	149,416	1,444	448,050
Khordha	711	5,482	10,954	1,439	-	18,586
Mayurbhanj	-	70	133	408	-	611
Puri	2,032	36,093	80,249	15,453	5	133,832
Grand Total	44,916	288,069	819,074	429,573	7,836	1,589,468

Details of the vulnerable infrastructure asset classes, public utilities, and essential facilities due to 2008 deep depression are summarized in

Table 5-27 and Table 5-28. The associated estimated losses of these vulnerable exposure classes are given in Table 5-29. Roads contributed highest losses of INR 290.88 crores (53%) followed by schools, which contributed INR 95.10 crores (17%) to the total losses of public utilities and infrastructure. Agriculture crop losses of about INR 1,068 crores have been estimated for this event.

Table 5-27: Affected public utilities and infrastructure due to 2008-Deep Depression in Odisha

District	Bridges	Railway Stations	Admin HQ	Fire Stations	Police Stations
Baleshwar	74	-	2	-	-
Bhadrak	16	-	3	1	1
Cuttack	59	-	5	1	0
Ganjam	12	-	1	-	-
Jagatsinghpur	36	4	4	1	3
Jajpur	32	-	2	0	2
Kendrapara	39	-	8	2	5
Khordha		-		-	-
Mayurbhanj		-	-	-	-
Puri	1	-	1	-	-
Grand Total	269	4	26	5	11

Table 5-28: Affected essential facilities and religious places due to 2008-Deep Depression in Odisha

Affected Districts	Schools Damaged			Hospitals Damaged			Cyclone Shelters Damaged			Religious Places Damaged		
	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%
Baleshwar	235	383	44	13	11	2	-	-	-	-	181	45
Bhadrak	135	683	26	13	87	7	-	2	-	-	111	4
Cuttack	366	903	164	221	295	33	-	-	-	-	167	25
Ganjam	10	59	-	2	9	-				-	16	1
Jagatsinghpur	307	1,365	194	34	211	19	-	2	2	-	177	15
Jajpur	193	969	39	25	110	2				-	193	14
Kendrapara	179	1,735	441	15	208	45	-	12	2	-	306	34
Khordha	52	81	1	44	25	-				-	10	-
Mayurbhanj	1	7	4	-	-	-				-	8	3
Puri	335	720	25	44	107	3	-	2	-	-	129	5
Grand Total	1,813	6,905	938	411	1,063	111	0	18	4	0	1,298	146

Table 5-29: Affected public utilities, essential facilities and infrastructure losses due to 2008-Deep Depression in Odisha

Affected Districts	Losses (INR Crore)													
	Schools	Hospitals	Bridges	Electricity Lines	Oil and Gas	Railway Lines	Railway Stations	Roads	Seaports	Religious Places	Admin Headquarter	Cyclone Shelters	Fire Stations	Police Stations
Baleshwar	4.9	0.1	6.3	0.0	0.4	0.8	-	8.7	-	0.7	0.1	0.0	-	-
Bhadrak	6.9	0.4	0.7	0.1	1.0	-	-	19.7	-	0.6	0.1	0.1	-	-
Cuttack	11.9	5.7	31.3	0.1	-	4.0	-	33.2	-	1.2	0.2	-	0.0	-
Ganjam	0.5	0.1	1.0	0.0	-	0.5	-	1.1	-	0.1	0.0	-	-	-
Jagatsinghpur	27.3	2.1	9.9	0.2	1.4	41.2	0.2	80.0	20.2	0.8	0.1	0.1	0.0	0.0

Affected Districts	Losses (INR Crore)													
	Schools	Hospitals	Bridges	Electricity Lines	Oil and Gas	Railway Lines	Railway Stations	Roads	Seaports	Religious Places	Admin Headquarter	Cyclone Shelters	Fire Stations	Police Stations
Jajpur	10.3	0.4	7.8	0.1	-	-	-	17.9	-	0.9	0.1	-	-	0.0
Kendrapara	25.9	0.9	12.0	0.4	3.6	-	-	110.8	-	1.3	0.3	0.2	0.0	0.0
Khordha	0.8	0.1	-	-	-	-	-	1.7	-	0.1	-	-	-	-
Mayurbhanj	0.1	-	-	-	-	-	-	0.1	-	0.0	-	-	-	-
Puri	6.6	0.5	0.3	0.1	-	0.6	-	17.7	-	0.6	0.0	0.0	0.0	-
Grand Total	**95.1**	**10.27**	**69.29**	**0.94**	**6.37**	**47.15**	**0.22**	**290.87**	**20.15**	**6.15**	**0.84**	**0.34**	**0.1**	**0.07**

The residential, commercial, and industrial building losses at village-level due to the 2008-deep depression are shown in Figure 5-13, Figure 5-14, and Figure 5-15 respectively.

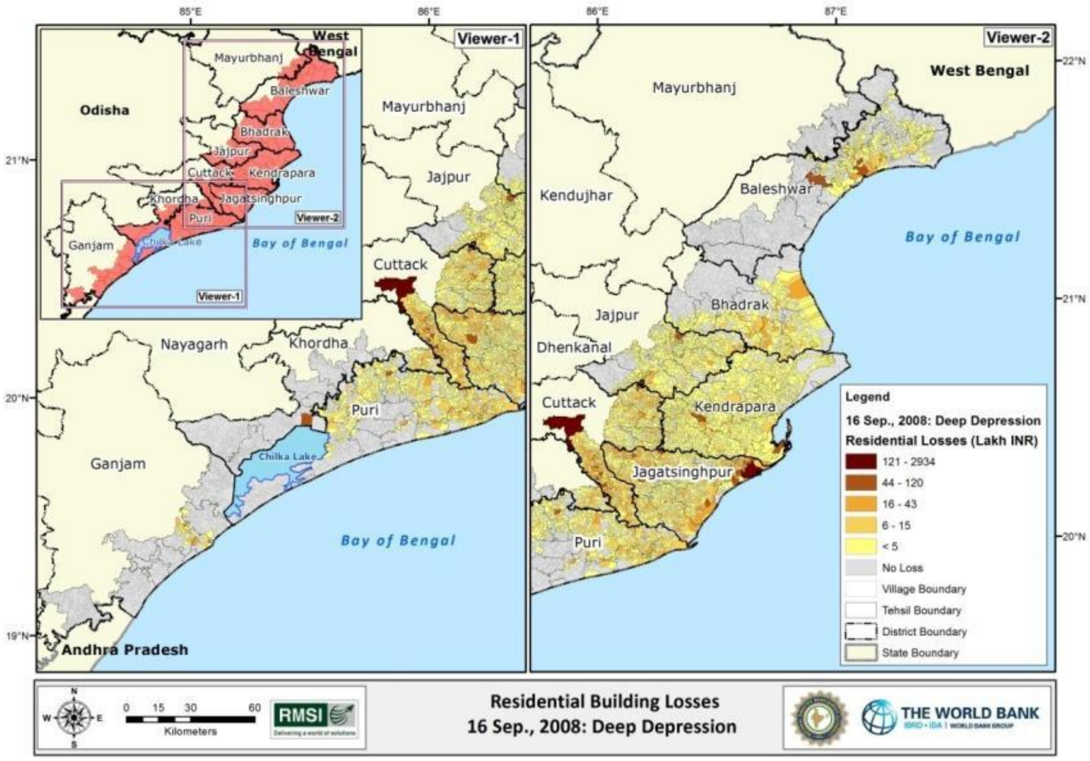

Figure 5-13: Estimated losses for cyclone induced rainfall flood due to 2008-Deep Depression for Residential Buildings

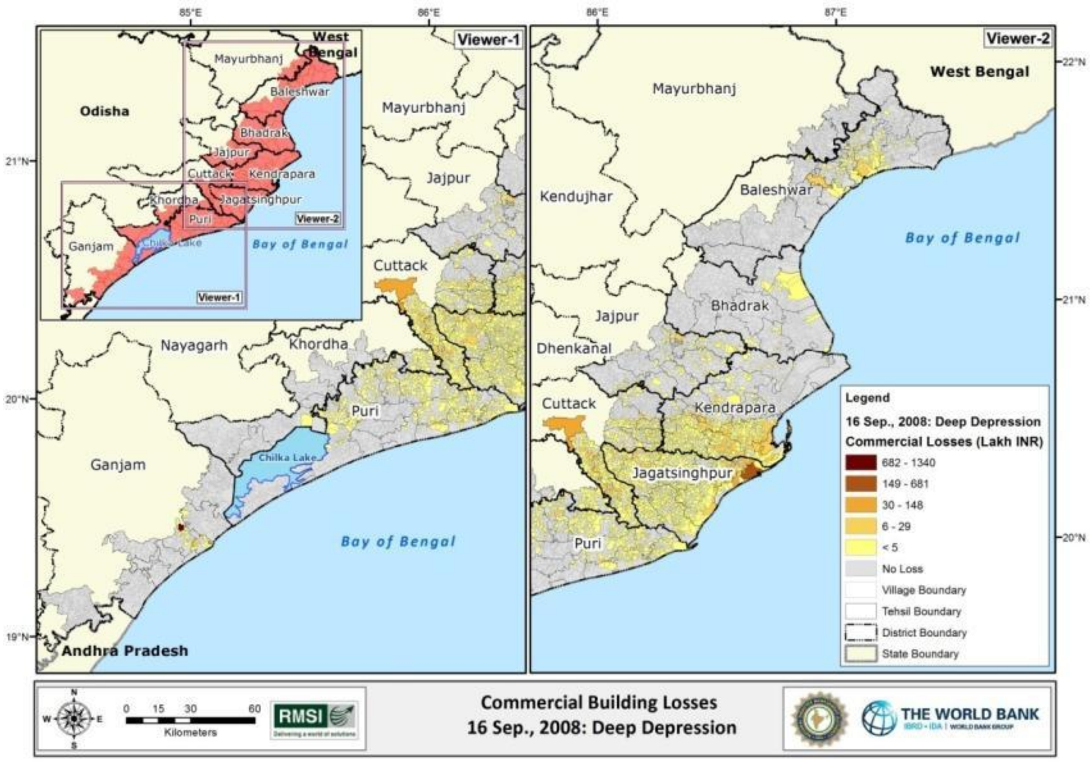

Figure 5-14: Estimated losses for cyclone induced rainfall flood due to 2008-Deep Depression for Commercial Buildings

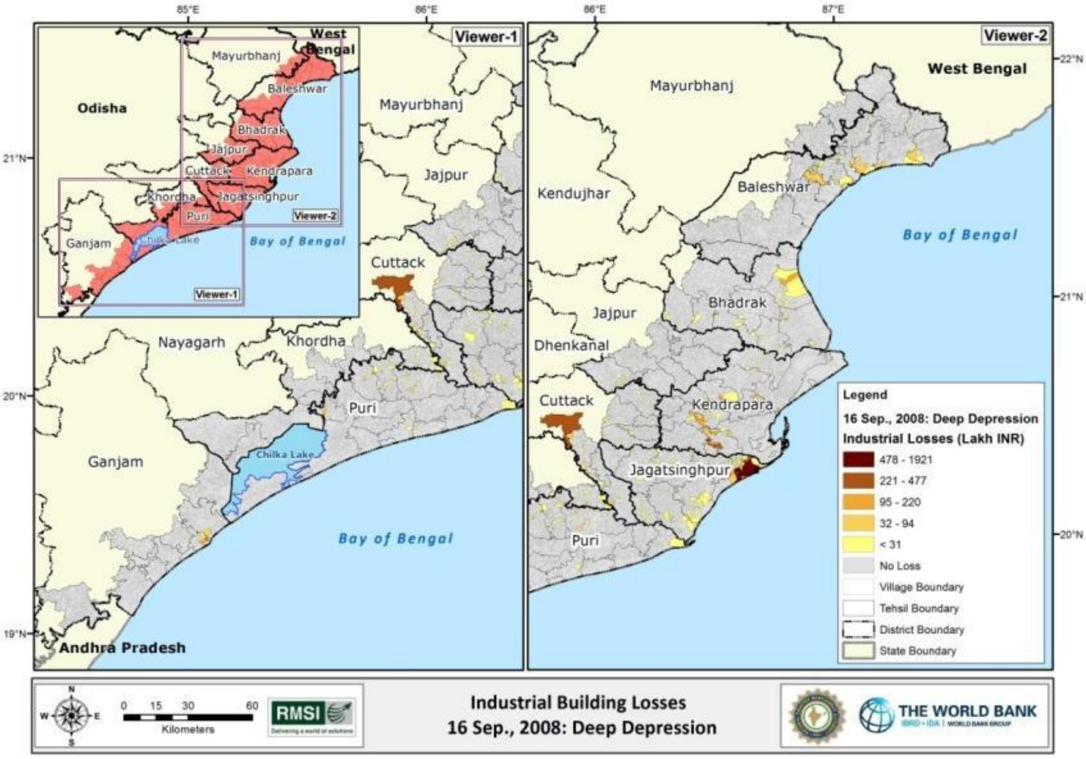

Figure 5-15: Estimated losses for cyclone induced rainfall flood due to 2008-Deep Depression for Industrial Buildings

The losses due to cyclonic wind and storm surge have not been reported for this event, as there was no significant contribution due to these hazards. A comparison between reported and estimated losses is given below.

5.2.2.1 Loss validation for 2008-deep depression

The comparison between estimated and reported losses from various sources has been given in Table 5-30. The table suggests that estimated losses are on the lower side, which may be attributed to the limited study area considered, which does not include the losses for affected exposure located above 10 m elevation. The number of estimated affected villages for ten districts is around 70% of the reported affected villages in 19 districts, whereas the estimated affected population is around 40% of the reported losses. The estimated affected population has been arrived at only for flood affected villages located below 10 m elevation, whereas the reported affected population has been reported for the entire flood affected area.

Table 5-30: Loss validation for 2008-Deep Depression

S. No.	Exposure Type	OSDMA, Govt. of Odisha[16]	UNEP Report, 2008	Estimated
1	Number of District Affected	19	19	10
2	Affected Population	45,23,590	42,02,064	15,89,468
3	Estimated Losses (Crore)	-	2,454	2,050
4	Affected Number of Villages	8,026	6,327	5,792

16 http://www.osdma.org/ViewDetails.aspx?vchglinkid=GL047&vchplinkid=PL060

S. No.	Exposure Type	OSDMA, Govt. of Odisha[16]	UNEP Report, 2008	Estimated
5	Total Agricultural Area Affected (ha)	-	4,44,990	4,27,224

5.2.3 Loss Estimates due to Hudhud Cyclone in Andhra Pradesh

Very severe cyclonic storm Huhud crossed north Andhra Pradesh coast over Visakhapatnam between 0630 and 0730 UTC of 12th October with maximum wind speed of 185 km/h. The tide gauge at Visakhapatnam reported the maximum storm surge of 1.4 meters above the astronomical tide. Hudhud caused extensive damage and loss of life in the city of Visakhapatnam and the neighboring districts of Vizianagaram and Srikakulam of Andhra Pradesh (IMD Report, 2014). This cyclone was very destructive and caused severe damage to property, school, power, trees, agricultural crops, etc. (Figure 5-16). Loss estimates due to winds and associated storm surge inundation are given below.

Figure 5-16: Damage photographs associated with VSCS Hudhud

Source: IMD Report, 2014

5.2.3.1 Loss estimates due to cyclonic winds

Details of loss estimates due to cyclonic wind speed associated with Hudhud in the study area for residential, commercial and industrial buildings are given in Table 5-31. It is clear from the table that Vishakhapatnam district was most affected in terms of economic losses due to cyclonic winds for residential, commercial and industrial buildings compared to other districts. However, estimated losses were relatively less for buildings located in

Vizianagaram and Srikakulam districts. The table also shows that residential building losses contribute higher wind losses as compared to the industrial and commercial building losses. About 93% losses for residential, 3% for commercial, and 4% for industrial building losses are contributed to the combined structural losses.

Table 5-31: Loss estimates for cyclonic wind due to Hudhud in Andhra Pradesh

Sl. No.	Affected Districts	Estimated Losses (INR Crores)			
		Residential	Commercial	Industrial	Combined Losses
1	East Godavari	51.18	1.83	3.65	56.66
2	Srikakulam	63.50	3.40	16.40	83.30
3	Vishakhapatnam	10,724.05	337.52	384.09	11,445.66
4	Vizianagaram	84.04	4.50	37.11	125.65
Grand Total		10,922.77	347.25	441.26	11,711.28

Details of affected districts, number of affected villages, households, and population are given in Table 5-32. The table shows that Vishakhapatnam was the worst affected district in Andhra Pradesh due to cyclonic winds associated to Hudhud with highest affected population, affected villages, and affected households. Detailed distribution of vulnerable households in various damage classes are given in Table 5-33.

Table 5-32: Vulnerable villages, households, and population for cyclonic winds due to Hudhud in Andhra Pradesh

Sl. No.	Affected Districts	Number of Affected Villages	Number of Affected Households	Affected Population	Affected Population (%)
1	East Godavari	18	31,360	12,94,485	33%
2	Srikakulam	86	34,460	5,07,526	31%
3	Vishakhapatnam	233	712,988	13,46,020	54%
4	Vizianagaram	83	46,663	1,17,853	64%
Grand Total		420	825,471	32,65,883	40%

Table 5-33: Vulnerable households in various damage classes for cyclonic winds due to Hudhud in Andhra Pradesh

Affected Districts	Estimated Damaged Households				
	<1%	1-5%	5-25%	25-40%	Total
East Godavari	6,52,460	8,033	145	-	6,60,638
Srikakulam	2,95,147	22,093	160	-	3,17,400
Vishakhapatnam	25,349	4,66,234	2,09,615	1,638	7,02,836
Vizianagaram	354	28,619	17,380	18	46,371
Grand Total	9,73,310	5,24,979	2,27,300	1,656	17,27,245

Details of the vulnerable infrastructure asset classes, public utilities, and essential facilities due to Hudhud induced winds are summarized in Table 5-34 and Table 5-35. The associated estimated losses of these vulnerable exposure classes due to Hudhud are given in Table 5-36. Seaports contribute the highest losses of INR 221.3 crores (56%) followed by schools which contribute INR 111.8 crores (28%) to the total losses of public utilities and infrastructure due to Hudhud in Andhra Pradesh.

Table 5-34: Affected public utilities and infrastructure for cyclonic winds due to Hudhud in Andhra Pradesh

Affected Districts	Airports	Seaports	Admin HQ	Police Stations
East Godavari	-	-	1	1
Guntur	-	-	-	-
Krishna	-	-	-	-
Prakasam	-	-	-	-
Sri Potti Sriramulu Nellore	-	-	-	-
Srikakulam	-	-	2	1
Vishakhapatnam	1	2	12	23
Vizianagaram	-	-	3	3
West Godavari	-	-	-	-
Grand Total	1	2	18	28

Table 5-35: Affected essential facilities and religious places for cyclonic winds due to Hudhud in Andhra Pradesh

Affected Districts	Damaged Schools					Damaged Hospitals					Damaged Religious Places			
	<1%	1%-5%	5%-25%	25%-40%	>40%	<1%	1%-5%	5%-25%	25%-40%	>40%	<1%	1%-5%	5%-25%	>25%
East Godavari	1,281	-	320	52	136	137	194	81	9	14	283	-	-	-
Srikakulam	228	848	1,092	136	164	49	195	229	22	34	609	2	-	-
Vishakhapatnam	-	-	-	28	1,658	-	-	-	12	346	41	176	14	-
Vizianagaram	-	-	-	-	365	-	-	-	-	70	4	79	-	-
Grand Total	1,509	848	1,412	216	2,323	186	389	310	43	464	937	257	14	-

Table 5-36: Losses for affected public utilities and infrastructure for cyclonic winds due to Hudhud in Andhra Pradesh

Affected Districts	Losses (INR crores)															
	Schools	Hospitals	Police Stations	Airports	Admin HQ	Electricity Lines	Fire Stations	Seaports	Railway lines	Railway Stations	Roads	Religious Places	Communication	Telecom Tower	Potable Water Systems	Waste Water Systems
East Godavari	2.12	0.17	-	-	0.02	1.15	-	0.37	0.05	0.20	0.02	0.14	-	0.38	0.01	-
Guntur	-	-	-	-	-	-	-	-	-	0.01	-	0.01	-	0.02	-	-
Krishna	-	-	-	-	-	-	-	-	-	-	-	0.01	-	0.04	-	-
Prakasam	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-
Sri Potti Sriramulu Nellore	-	-	-	-	-	-	-	0.05	-	-	-	0.01	-	0.03	-	-
Srikakulam	2.59	0.29	0.01	-	0.03	2.22	-		0.02	0.02	0.04	0.19	0.01	0.67	0.01	0.01
Vishakhapatnam	100.68	21.21	0.79	59.79	0.56	92.37	0.10	220.91	3.69	12.07	1.45	4.74	0.48	12.55	0.99	0.58
Vizianagaram	6.42	0.27	0.01	-	0.09	4.39	-		-	-	0.10	0.41	0.01	1.79	0.04	0.02
West Godavari	-	-	-	-	-	-	-		-	0.01	-	0.02	-	0.04	-	-
Grand Total	111.80	21.95	0.81	59.79	0.70	100.13	0.10	221.33	3.77	12.33	1.62	5.53	0.50	15.53	1.06	0.62

The residential, commercial, and industrial buildings losses at village-level due to cyclonic winds associated to cyclonic storm Hudhud are shown in Figure 5-17, Figure 5-18, and Figure 5-19, respectively.

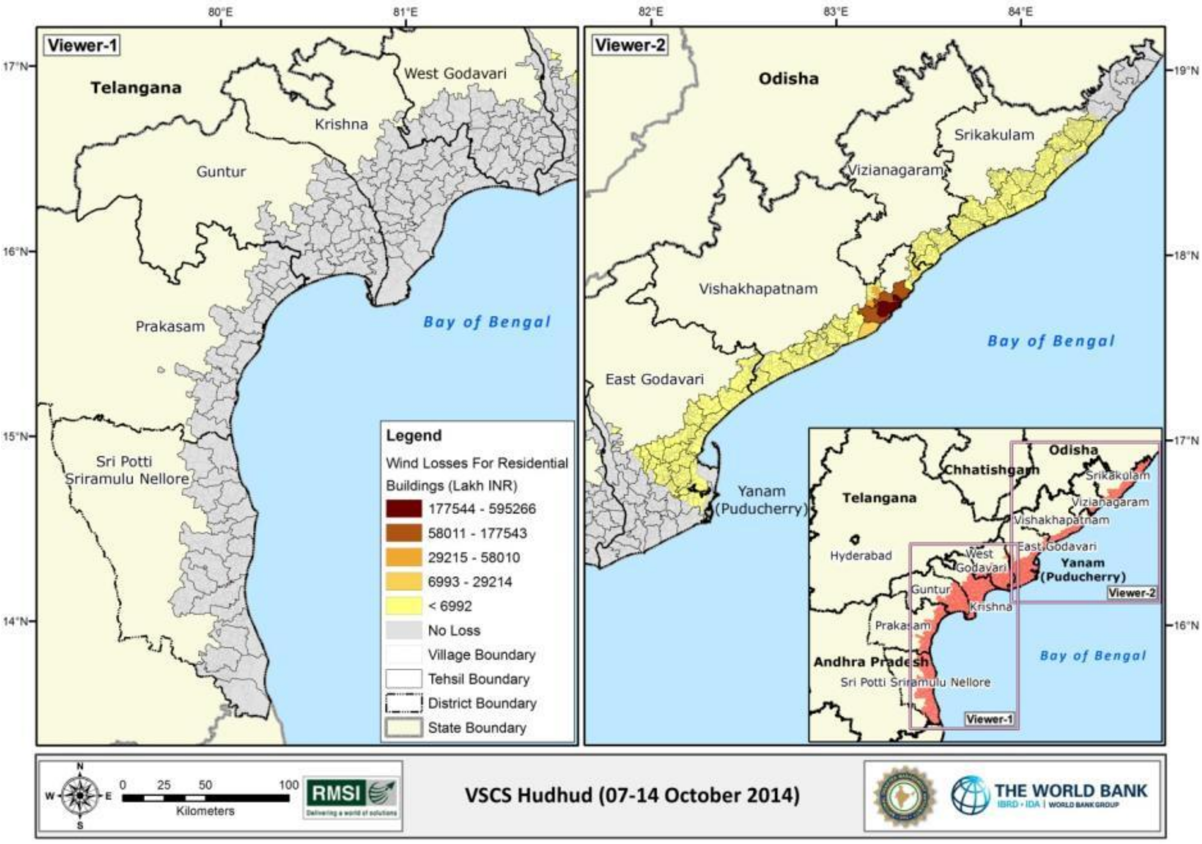

Figure 5-17: Estimated losses for cyclonic winds due to Hudhud for residential buildings

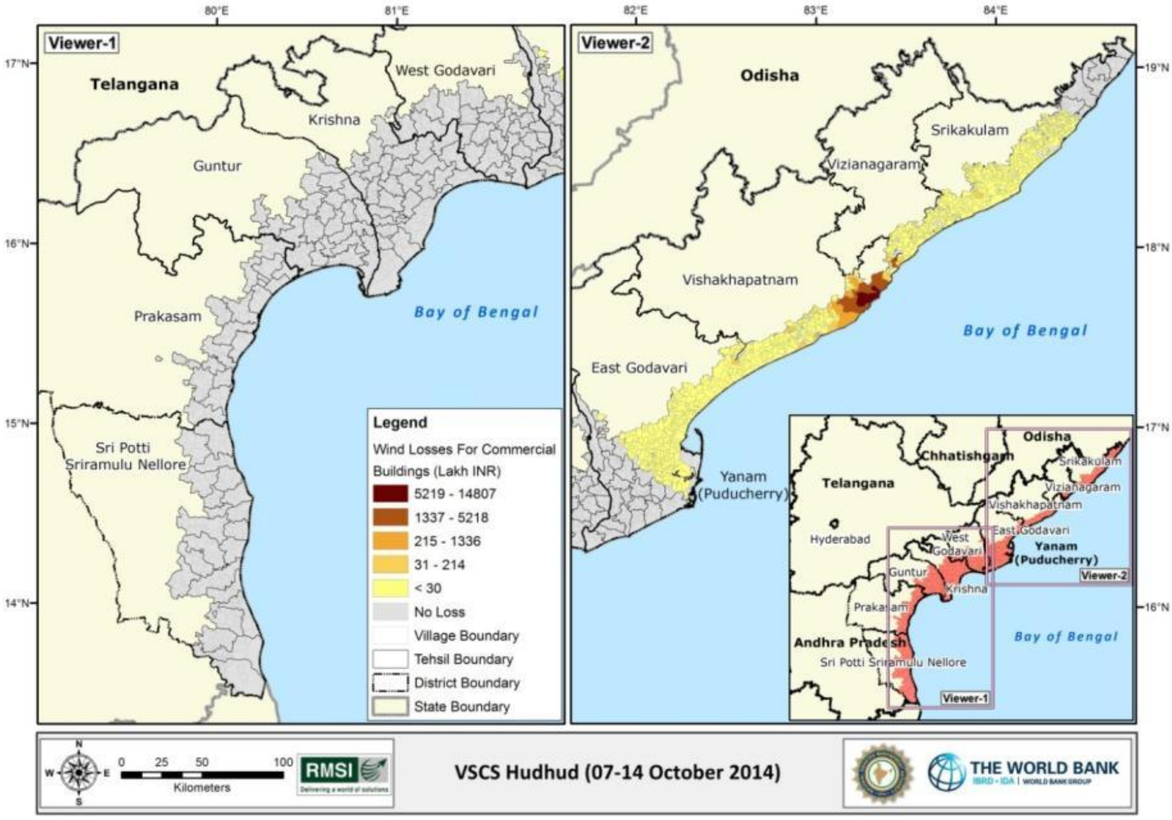

Figure 5-18: Estimated losses for cyclonic winds due to Hudhud for commercial buildings

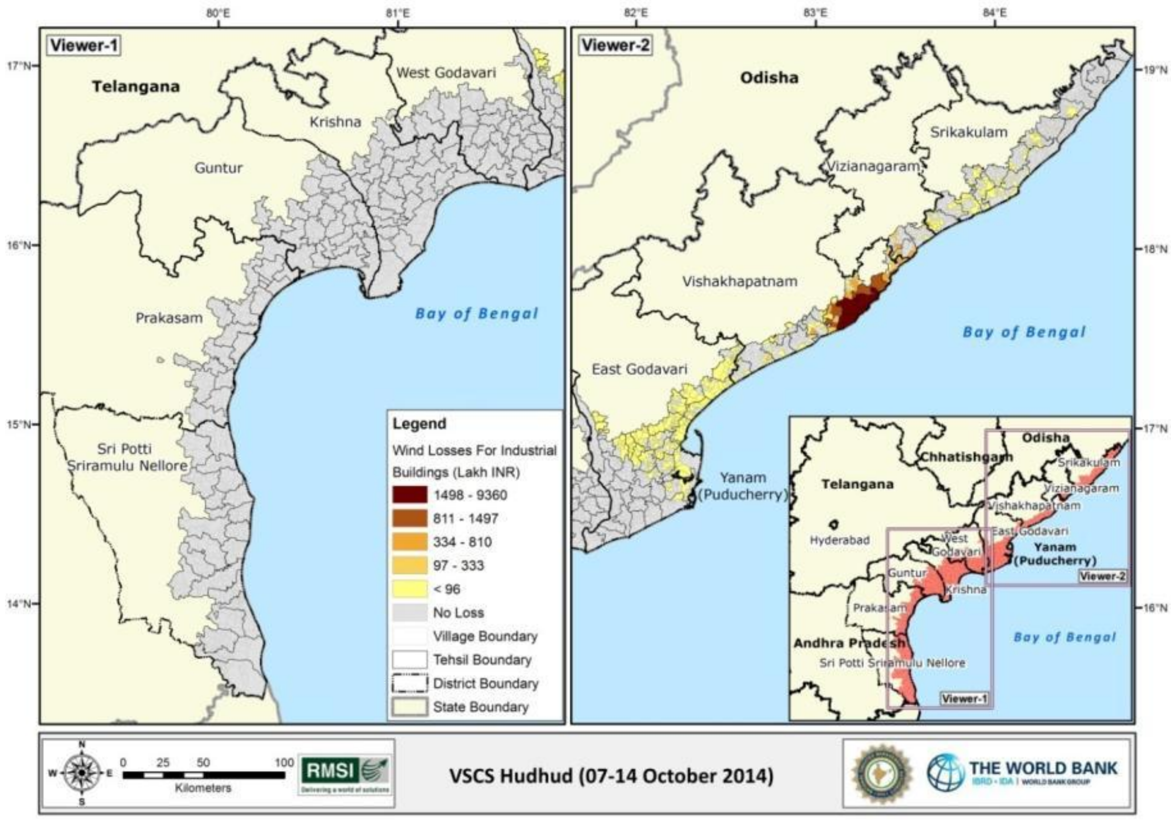

Figure 5-19: Estimated losses for cyclonic winds due to Hudhud for industrial buildings

5.2.3.2 Loss estimates due to storm surge

Details of loss estimates due to storm surge inundation for Hudhud in the study area for residential, commercial and industrial buildings are given in Table 5-37. It is clear from the table that Vishakhapatnam district was most affected in terms of economic losses due to cyclonic winds for residential, commercial and industrial buildings compared to other districts. The table also shows that industrial building losses contribute higher storm surge losses as compared to the residential and commercial building losses. Industrial, residential, and commercial building losses contribute about 69%, 19%, and 13% losses respectively to the combined structural losses.

Table 5-37: Loss estimates for storm surge due to Hudhud in Andhra Pradesh

Sl. No.	Affected Districts	Estimated Losses (INR Crore)			
		Residential	Commercial	Industrial	Combined Losses
1	East Godavari	0.16	0.02	0.02	0.2
2	Prakasam	0.17	-	-	0.17
3	Sri Potti Sriramulu Nellore	0.08	-	-	0.08
4	Srikakulam	0.16	0.01	-	0.17
5	Vishakhapatnam	1.45	0.52	0.35	2.32
6	West Godavari	0.01	-	-	0.01
Grand Total		2.03	0.55	0.37	2.95

Details of affected districts, number of affected villages, households, and population due to storm surge are given in the Table 5-38, which shows that Vishakhapatnam was the worst affected district in Andhra Pradesh by cyclonic winds associated to Phailin with highest affected population, affected villages, and affected households.

Table 5-38: Vulnerable villages, households and population for storm surge due to Hudhud in Andhra Pradesh

Sl. No.	Affected Districts	Number of Affected Villages	Number of Affected Households	Affected Population	Affected Population (%)
1	East Godavari	52	86	310	0.01%
2	Guntur	6	2	7	0.00%
3	Krishna	17	5	17	0.00%
4	Prakasam	22	68	240	0.02%
5	Sri Potti Sriramulu Nellore	43	72	275	0.01%
6	Srikakulam	80	21	83	0.01%
7	Vishakhapatnam	34	131	468	0.02%
8	Vizianagaram	7	2	9	0.00%
9	West Godavari	4	3	10	0.00%
Grand Total		265	389	1,419	0.01%

Details of the vulnerable infrastructure asset classes, public utilities and essential facilities for storm surge inundation due to Hudhud are summarized in Table 5-39 and Table 5-40. The associated estimated losses of these vulnerable exposure classes due to Hudhud are given in Table 5-41. The table shows that schools contribute highest losses of INR 106.97 crore (56%) followed by airport which contribute INR 59.79 crore (31%) to the total losses of public utilities and infrastructure due to Hudhud in Andhra Pradesh. However, in schools, estimated percentage losses are less than 5 percent, which does not affect the functionality of a school.

Table 5-39: Vulnerable public utilities and infrastructure for storm surge due to Hudhud in Andhra Pradesh

Affected Districts	Schools	Hospitals	Seaports	Religious Places	Admin HQ	Cyclone Shelters
East Godavari	-	-	1	-	-	-
Guntur	-	-	-	-	-	-
Krishna	-	-	-	-	-	-
Prakasam	-	-	-	-	-	-
Sri Potti Sriramulu Nellore	-	-	1	-	1	-
Srikakulam	13	3	-	10	-	-
Vishakhapatnam	736	46	2	16	-	-
Vizianagaram	47	8	-	7	-	-
West Godavari	-	-	-	-	-	-
Grand Total	796	57	4	33	1	0

Table 5-40: Vulnerable essential facilities and religious places for storm surge due to Hudhud in Andhra Pradesh

Affected Districts	Estimated Damaged Schools			Estimated Damaged Hospitals			Estimated Damaged Religious Places		
	<1%	1%-5%	>5%	<1%	1%-5%	>5%	<1%	1%-5%	>5%
East Godavari	430	0	-	72	0	-	39	0	-
Guntur	46	0	-	7	0	-	3	0	-
Krishna	114	0	-	14	0	-	13	0	-
Prakasam	331	0	-	42	0	-	22	0	-
Sri Potti Sriramulu Nellore	232	0	-	71	0	-	30	0	-
Srikakulam	533	13	-	67	3	-	68	10	-
Visakhapatnam	76	736	-	26	46	-	18	16	-
Vizianagaram	0	47	-	0	8	-	0	7	-
West Godavari	75	0	-	14	0	-	4	0	-
Grand Total	1,837	796	0	313	57	0	197	33	0

Table 5-41: Losses for affected public utilities and infrastructure for storm surge due to Hudhud in Andhra Pradesh

Affected Districts	Losses (INR Crores)										
	Schools	Hospitals	Admin HQ	Cyclone Shelters	Sea Ports	Airports	Roads	Religious Places	Commun ication	Potable Water Systems	Waste Water Systems
East Godavari	33.24	1.49	-	-	0.67	-	0.01	0.93	0.11	0.03	0.03
Guntur	0.30	0.02	-	-	-	-	-	0.04	0.01	-	-
Krishna	0.71	0.27	-	-	-	-	-	0.10	0.02	0.01	0.01
Prakasam	4.65	0.31	-	-	-	-	-	0.55	0.10	0.01	0.01
Sri Potti Sriramulu Nellore	1.63	0.20	0.01	-	0.35	-	-	0.31	0.05	0.02	0.01
Srikakulam	5.42	0.49	-	-	-	-	-	0.45	0.09	0.02	0.02
Vishakhapatnam	60.09	14.31	-	-	0.57	59.79	-	1.54	1.55	0.27	0.42
Vizianagaram	0.42	0.01	-	-	-	-	-	0.06	0.01	0.01	0.01
West Godavari	0.51	0.02	-	-	-	-	-	0.09	0.02	0.01	-
Grand Total	106.97	17.12	0.01	0	1.59	59.79	0.01	4.07	1.94	0.38	0.51

The residential, commercial, and industrial building losses at village-level due to storm surge inundation associated with Hudhud are shown in Figure 5-20, Figure 5-21, and Figure 5-22, respectively.

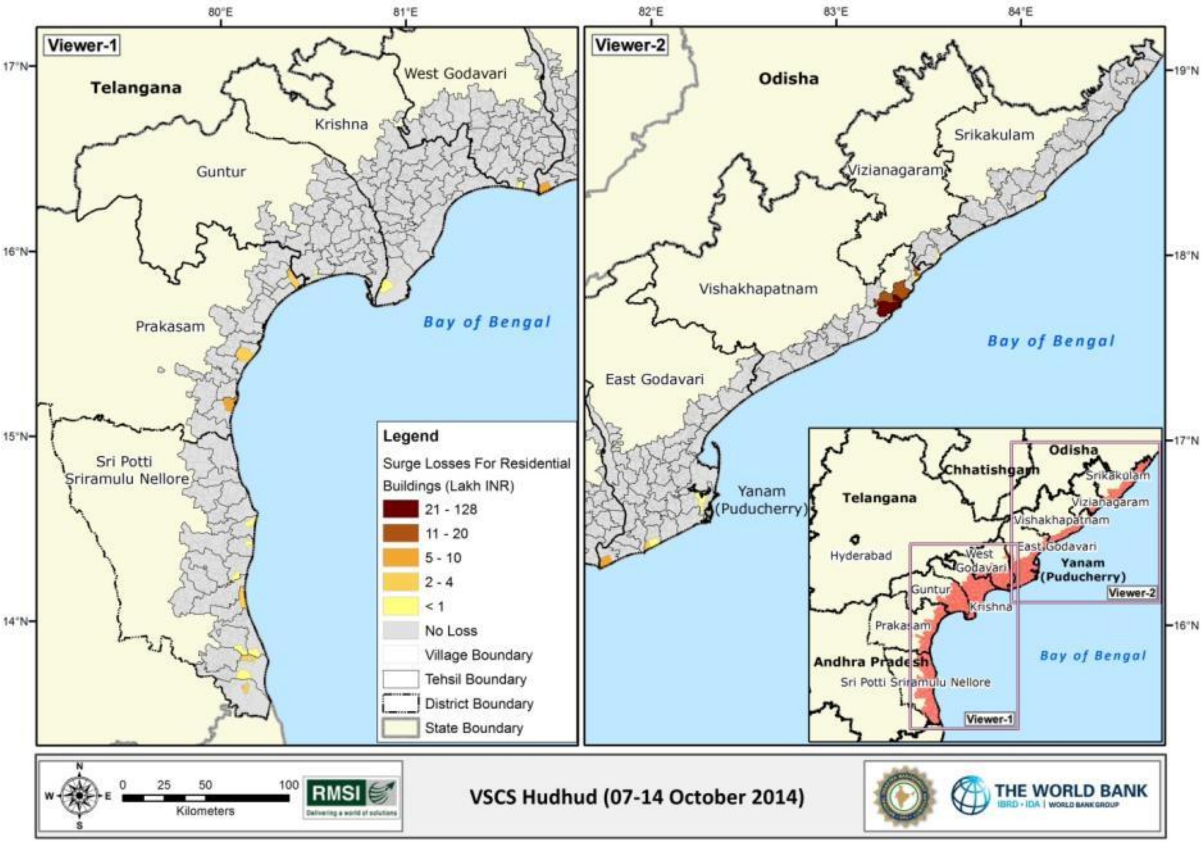

Figure 5-20: Estimated losses for storm surge due to Hudhud for residential buildings

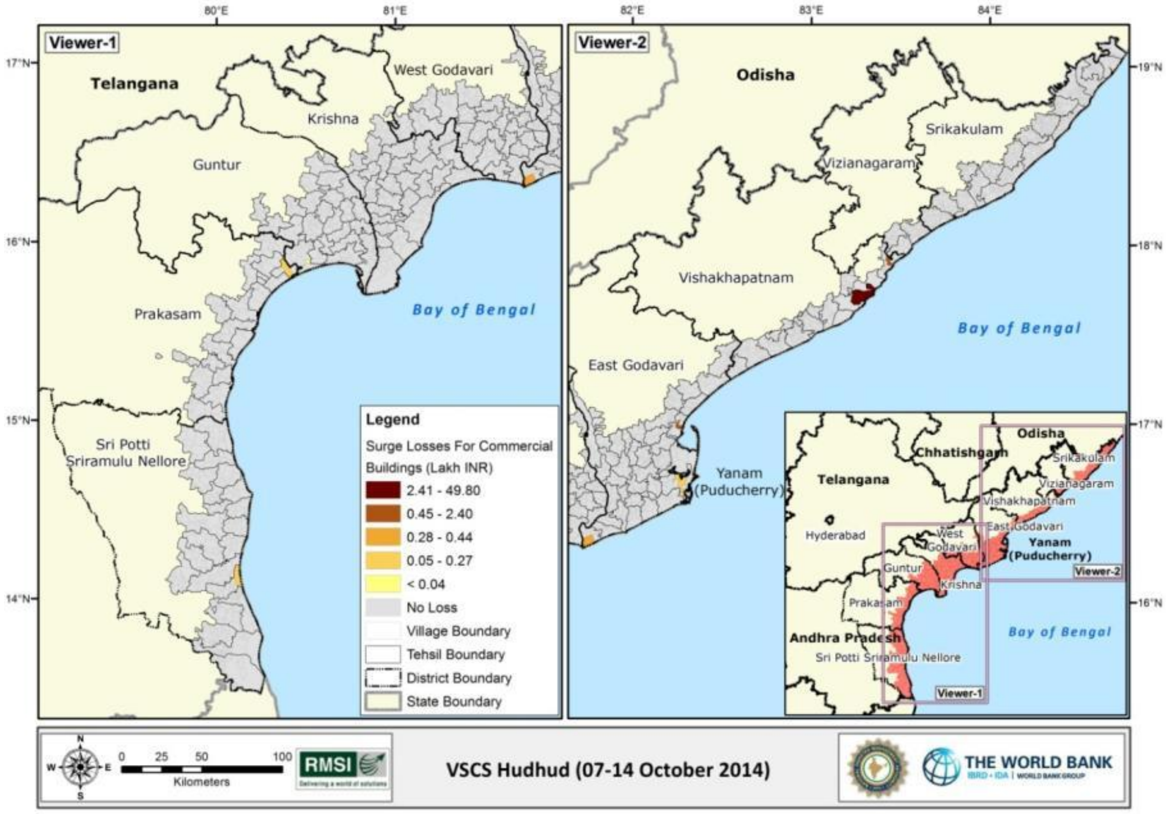

Figure 5-21: Estimated losses for storm surge due to Hudhud for commercial buildings

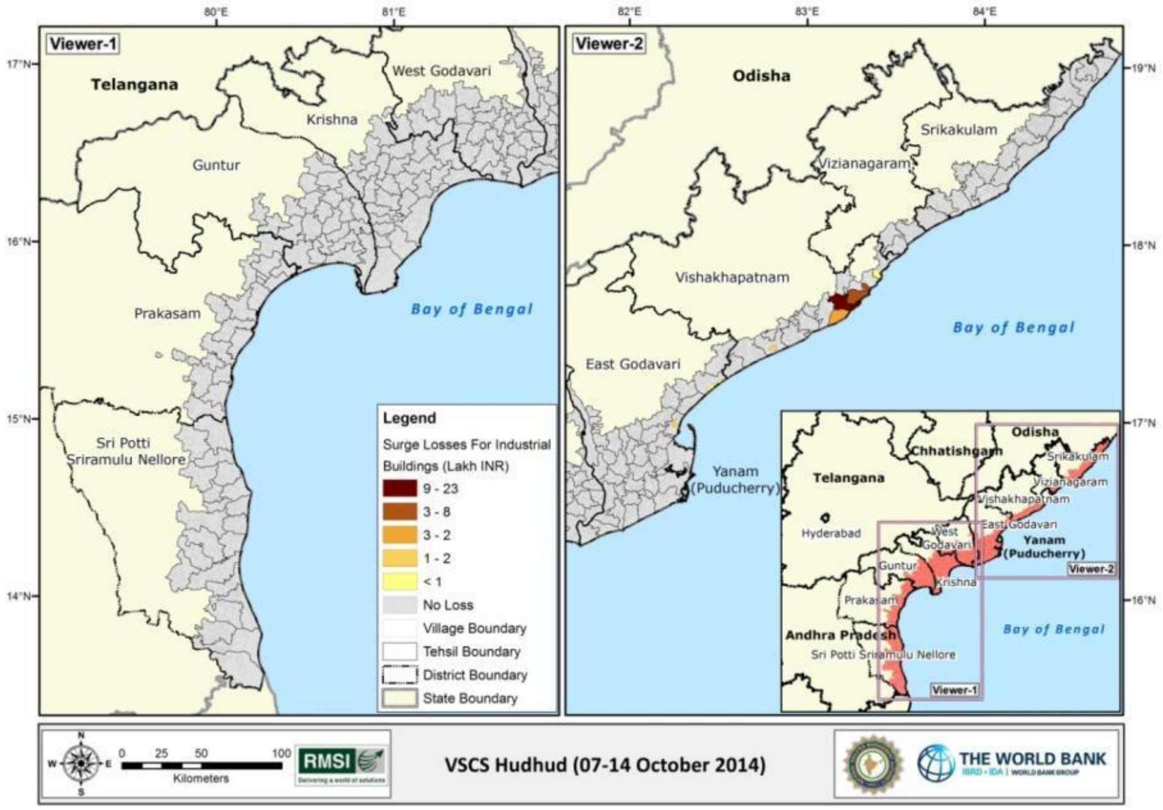

Figure 5-22: Estimated losses for storm surge due to Hudhud for industrial buildings

As far as the severity of rainfall is concerned, it was mainly concentrated on Vizianagaram and Visakhapatnam districts of Andhra Pradesh. There is no major river stream located in these areas. Losses from flood due to cyclone-induced rainfall have not been reported for this event. Therefore, cyclone induced rainfall flood hazard has not been estimated for this event.

5.2.3.3 Validation of modeled crop losses

Figure 5-23 shows reported rice and cotton crop production losses and modeled losses due to Hudhud cyclone induced rainfall for four districts combined (Visakhapatnam, Vizianagaram, Srikakulam, and East Godavari). Variation between reported and model estimated rice and cotton crop production losses are 10% and -11% respectively, which represent quite a good estimation.

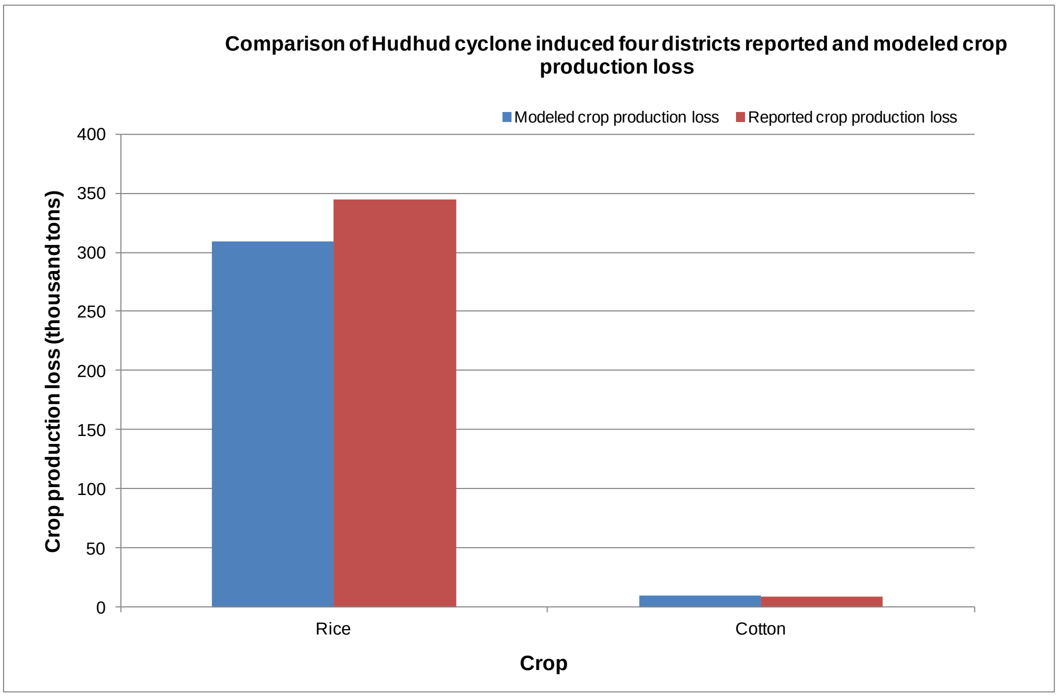

Figure 5-23: Comparison of reported crop production losses and modeled losses for Hudhud cyclone induced rainfall for four districts combined (Visakhapatnam, Vizianagaram, Srikakulam, and East Godavari)

It should be noted that cyclone induced losses were estimated for each district and then the combined to get the four district losses to compare the reported losses and modeled losses. This was because we received Hudhud cyclone induced reported crop production losses for aggregated four affected districts (Visakhapatnam, Vizianagaram, Srikakulam, and East Godavari). In this report we have shown comparison results only for two major crops (rice and cotton) grown in the coastal districts of Andhra Pradesh as Hudhud cyclone caused maximum damage to these two crops, which was about 80% of total affected acreage. Besides, there seems to be some issue in the reported losses for other crops as reported acreage losses and reported production losses do not match well. For example, normal yield of groundnut in these districts is about 0.9 t/ha, but in case of reported yield loss it is only 0.28 although there has been damage to total cropped area. Another example is for green gram. In this case, normal yield is about 0.5 t/ha and reported yield loss is only 0.22 t/ha. This might be due to some error in the estimation of the losses or in recording. Some crops were not included in the validation exercise due to very minor reported losses for the event (e.g., Black gram, Jowar, and Bajra).

In general, there is a good match in the numbers of damaged buildings, infrastructural elements (despite difference in study area extent in reported districts). However, modeled loss estimates have large variations as compared to the RDNA report (RDNA, 2014)[17] as losses reported in the RDNA report are based on simplified assumptions. For example, for damaged houses in Cyclone Hudhud (RDNA, 2014), reconstruction cost is taken as INR. 4.0 lakhs and INR 3.0 lakhs, respectively for urban and rural houses that are fully/severely damaged with an assumed average area of 30 and 22 square meters, respectively. This provides much lower estimates of built-up housing area than actual. Moreover, RDNA (2014) reconstruction cost is only for those houses that are fully/severely damaged and these are far lower in numbers than the number of partially damaged houses.

5.2.3.4 Loss validation for Cyclone Hudhud

The reported losses from various available sources for 2014-Hudhud cyclone have covered the entire affected area in contrast to this study where losses are estimated only for the districts which are located up to 10-m elevation from the coastal line. Hence, considering this, a variation in losses has been observed when estimated losses are compared with reported losses for the event.

The comparison between estimated and reported losses from various available sources has been given in Table 5-42. The estimated losses presented here are the combined impact of winds and associated surges on exposed assets in the study area. The losses have been estimated for nine districts of Andhra Pradesh for this event. Out of nine districts, only four districts, namely, East Godavari, Srikakulam, Vishakhapatnam, and Vizianagaram show contributions to total estimated losses for this event. The post storm survey reports also stated that these four districts were impacted due to Hudhud. A variation in the count of affected population is attributed due to the limited area considered. However, the extent of strong gale winds due to Hudhud covered the adjoining districts of south Odisha and north Andhra Pradesh also and the losses in these regions are outside the present study's area of interest.

Table 5-42: Loss validation for 2014-Hudhud Cyclone

S. No.	Exposure Type	Reported Losses[18]	Estimated Losses
1	Number of District Affected	4	4
2	Population Affected	9,200,000	3,265,883
3	Houses/ Households Damaged	135,063	228,956
4	Total Losses (Crore)	13,263	11,711
5	Affected number of Villages	4,484	685
6	Affected Number of Schools	1521	2,539
7	Industrial Losses (Crore)	2499	442

5.2.4 LOSS ESTIMATES DUE TO CYCLONIC STORM "PYARR" IN ANDHRA PRADESH

Cyclone Pyarr crossed north Andhra Pradesh coast close to Kalingapatnam on the morning of 19th September 2005. It remained as a cyclonic storm over north coastal Andhra Pradesh close to Kalingapatnam till the evening of the same day. It then moved west-northwest wards and weakened gradually into a deep depression and then a depression.

[17] RDNA (2014). Rapid Damage and Needs Assessment Report, INDIA Hudhud in Andhra Pradesh, October 2014. A report published by the ADB, Govt. of Odisha, and the World Bank, Dec., 2014.

[18] IMD Report (2014), Very Severe Cyclonic Storm, HUDHUD over the Bay of Bengal (07 - 14 October 2014): A Report

Under the influence of the depression, very heavy rainfall occurred during 12 to 15 September in Odisha, Chattisgarh, and Madhya Pradesh. Torrential rainfall affected eastern coastal India, with a daily peak of 490 mm in Kunavaram. Due to tremendous flooding, 315 villages were affected and a large number of people were forced to relocate after the Godavari and Krishna rivers burst their banks in Andhra Pradesh.

Severity of the flood caused by the 2005 event is shown in the photographs in Figure 5-24.

Figure 5-24: Flood damage photographs associated with 2005 flooding in Andhra Pradesh

Details of loss estimates due to cyclone Pyarr in the study area for Residential, Commercial and Industrial building are given in Table 5-43. This table shows the highest residential building losses of INR 44 crores in East Godavari and INR 31 crores in Srikakulam. Highest commercial losses of INR 2.2 and INR 1.2 crores for East Godavari and Srikakulam have been estimated respectively. The table also shows that residential and industrial building losses contribute higher flood losses as compared to the commercial building losses. Residential, Commercial, and Industrial building losses contribute about 83%, 4%, and 13% losses respectively to the combined structural losses.

Table 5-43: Loss estimates of cyclone induced rainfall flood due to 2005-Pyarr Cyclone in Andhra Pradesh

Sl. No.	Affected Districts	Losses (INR crores)			
		Residential	Commercial	Industrial	Combined Losses
1	East Godavari	44.0	2.2	10.6	56.71
2	Guntur	11.2	0.7	0.1	11.89
3	Krishna	9.8	0.3	1.2	11.37
4	Srikakulam	31.0	1.2	2.7	34.87
5	Vishakhapatnam	4.6	1.0	0.9	6.43
6	Vizianagaram	0.1	-	-	0.08
7	West Godavari	0.9	0.1	0.2	1.14
	Grand Total	**101.5**	**5.3**	**15.6**	**122.50**

Details of the affected districts, number of affected village, households, and population are given in Table 5-44. The table shows that East Godavari was the worst affected district in Andhra Pradesh by cyclone induced rainfall flooding due to 2005-Pyaar cyclone with highest affected population, affected villages, and affected households.

Table 5-44: Vulnerable population and households due to 2005-Pyaar cyclone in Andhra Pradesh

Sl. No.	Affected Districts	Number of Affected Villages	Number of Affected Households	Affected Population	Affected Population (%)
1	East Godavari	108	20,652	74,350	22%
2	Guntur	66	7,533	27,958	9%
3	Krishna	43	4,796	18,158	6%
4	Srikakulam	74	6,517	22,608	10%
5	Vishakhapatnam	25	2,288	5,854	8%
6	Vizianagaram	2	21	107	11%
7	West Godavari	18	863	3,091	4%
	Grand Total	336	42,670	1,52,125	12%

Details of the vulnerable infrastructure asset classes, public utilities, and essential facilities due to cyclone Pyarr are summarized in Table 5-45 and Table 5-46. The associated estimated losses of these vulnerable exposure classes due to cyclone Pyarr are given in Table 5-47. Roads contribute the highest losses of INR 84.15 crores (28%) followed by power plants which contribute INR 55.25 crores (18%) to the total losses of public utilities and infrastructure due to 2005-Pyarr cyclone in Andhra Pradesh. Agriculture crops losses of about INR 910 crores have been estimated for this event.

Table 5-45: Affected public utilities and infrastructure due to 2005-Cyclonic Storm in Andhra Pradesh

District	Bridges	Admin HQ	Police Stations	Power Plants
East Godavari	34	2	3	1
Guntur	20	3		-
Krishna	12	2		-
Prakasam				-
Nellore				-
Srikakulam	11			-
Vishakhapatnam	11	1		-
Vizianagaram	4		-	-
West Godavari	7	-	1	-
Grand Total	99	8	4	1

Table 5-46: Affected essential facilities and religious places due to 2005-Cyclonic Storm in Andhra Pradesh

District	Schools Damaged			Hospitals Damaged			Cyclone Shelters Damaged			Religious Places Damaged		
	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%
East Godavari	153	568	0	67	257	0	-	7	9	-	74	56
Guntur	72	372	0	31	117	0	-	21	4	-	37	9
Krishna	85	167	1	52	58	1	-	9	3	-	28	19
Prakasam	-	-	0	-	-	-				-	3	
Nellore	-	-	27	-	-	10	-	-	-	-	2	1

District	Schools Damaged			Hospitals Damaged			Cyclone Shelters Damaged			Religious Places Damaged		
	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%	<1 %	1% - 5%	>5%
Srikakulam	63	-	188	27	-	97			-	-	92	4
Vishakhapatnam	10	32	57	7	28	24	-	1	-	-	41	1
Vizianagaram	1	-	41	-	-	14	-	-	-	-	14	1
West Godavari	6	42	-	3	17	0	-	-	2	-	15	22
Grand Total	390	1,181	314	187	477	146	0	38	18	0	306	113

Table 5-47: Affected public utilities, infrastructure, and essential facilities losses due to 2005-Cyclonic Storm in Andhra Pradesh

District	Losses (INR crores)														
	Schools	Hospitals	Airports	Bridges	Electric Lines	Oil and Gas	Portable Water	Railway Lines	Roads	Waste Water	Religious Places	Admin Headquarters	Cyclone Shelters	Police Stations	Power Plants
East Godavari	12.53	1.57	-	56.1	0.16	2.93	4.96	16.5	57.5	3.87	1.57	0.17	0.12	0.01	55.25
Guntur	7.45	0.39	-	11.23	0.07	-	1.44	5.41	12.57	0.98	0.63	0.12	2.26	0	-
Krishna	2.98	0.51	-	4.45	0.02	-	0.82	0.09	8.52	0.81	0.4	0.04	0.6	-	-
Prakasam	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-
Nellore	0.15	0.22	-	-	-	-	-	-	1.16	-	0.06	-	-	-	-

District	Losses (INR crores)														
	Schools	Hospitals	Airports	Bridges	Electric Lines	Oil and Gas	Portable Water	Railway Lines	Roads	Waste Water	Religious Places	Admin Headquarters	Cyclone Shelters	Police Stations	Power Plants
Srikakulam	3.26	0.38	-	0.71	0.01	-	0.12	2.34	2.06	0.12	0.18	-	-	-	-
Vishakhapatnam	2.12	0.44	4.43	0.16	0.01	-	0.13	0.2	0.76	0.11	0.08	0.02	0.01	-	-
Vizianagaram	0.18	0.26	-	0.34	0	-	0.01	-	0.15	0.01	0.02	-	-	-	-
West Godavari	1.94	0.09	-	2.61	0.01	0.17	0.4	1.17	1.43	0.26	0.2	-	0.03	0	-
Grand Total	30.61	3.86	4.43	75.6	0.28	3.1	7.88	25.71	84.15	6.16	3.15	0.35	3.02	0.01	55.25

The residential, commercial, and industrial building losses at village-level due to the 2005-cyclonic storm are shown in Figure 5-25, Figure 5-26, and Figure 5-27 respectively.

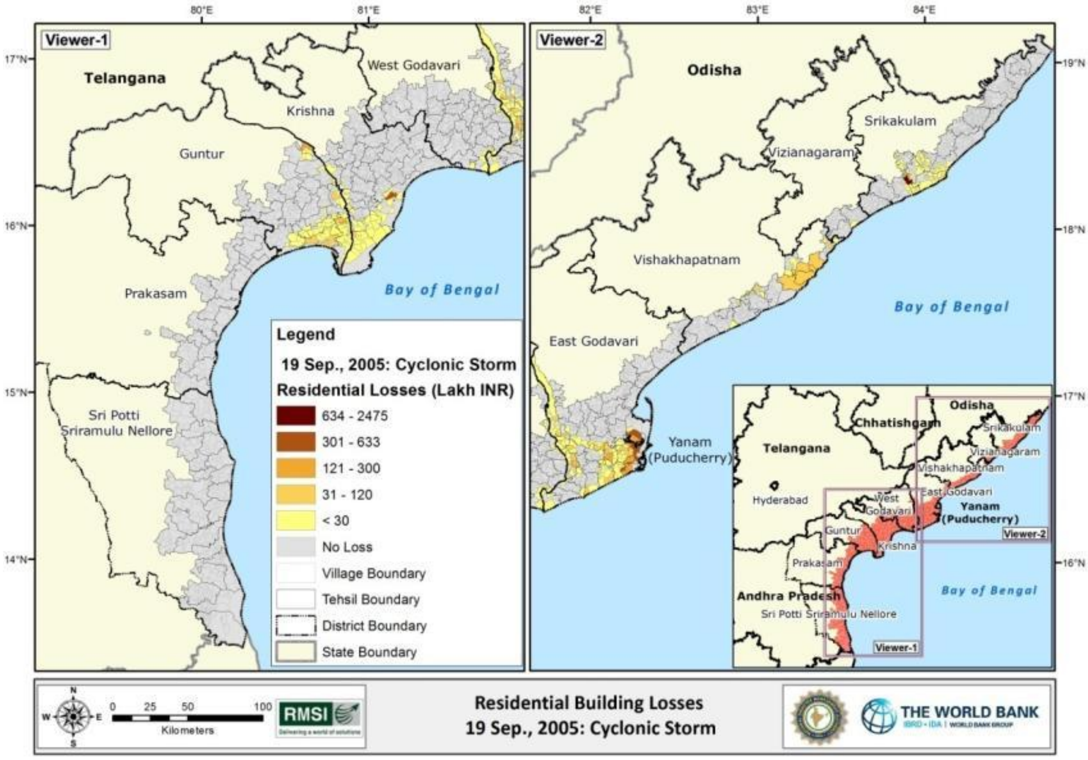

Figure 5-25: Estimated losses for cyclone induced rainfall flood due to 2005-Pyarr Cyclone for Residential Buildings

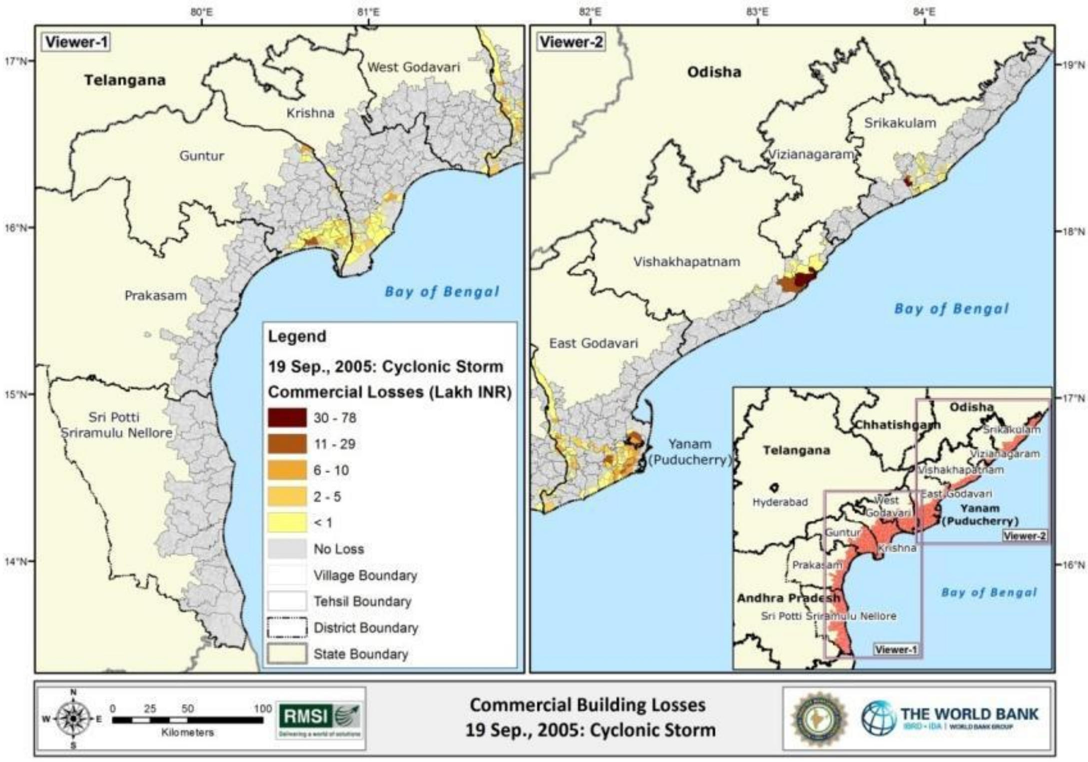

Figure 5-26: Estimated losses for cyclone induced rainfall flood due to 2005-Pyarr Cyclone for Commercial Buildings

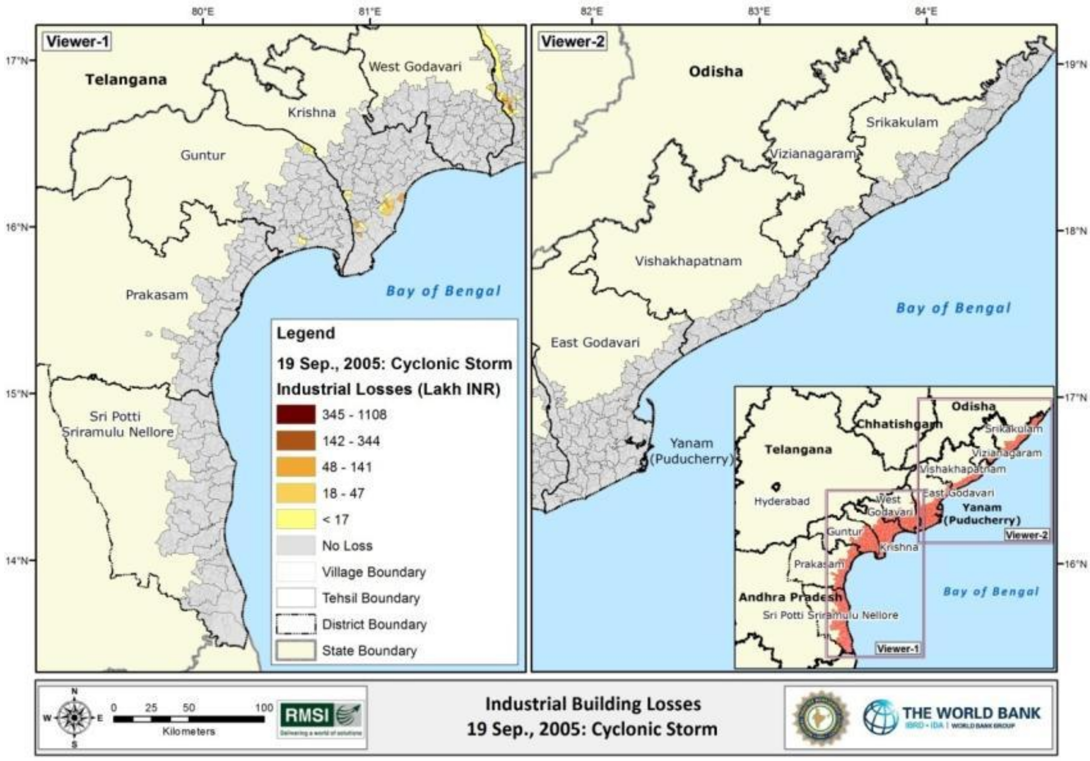

Figure 5-27: Estimated losses for cyclone induced rainfall flood due to 2005-Pyarr Cyclone for Industrial Buildings

As mentioned above, the cyclone Pyarr crossed the coast close to Kalingapatnam with maximum wind speed of 65 km/h. Since the severity of cyclone Pyarr was not significant, no losses were found due to cyclonic wind and associated surge. A detail comparison between reported and estimated losses is given below.

5.2.4.1 Loss validation for Pyarr Cyclone

The reported losses from various available sources for 2005-Pyarr cyclone have covered the entire affected area in contrast to this study where losses are estimated only for the districts, which are located up to 10-m elevation from the coastal line. Hence, considering this, a variation has been observed when these losses are compared with reported losses for the same flood event. Besides, no significant losses due to cyclonic wind and storm surge have been reported for this event.

The comparison between estimated and reported losses from various available sources has been given in Table 5-48. The table suggests that estimated losses are on the lower side, which are attributed to the limited study area considered, which do not include losses for affected exposure located above 10 m elevation.

Table 5-48: Loss validation for Pyarr Cyclone

S. No.	Exposure Type	Reported (RDM, Govt. of AP)[19]	Reported, DST, 2005-06	Estimated
1	Number of District Affected	10	11	7
2	Population affected	350,000	-	152,125
3	Households Affected	118,618	-	42,670
4	Estimated Losses (Crore)	-	1,809	1,336

[19] http://disastermanagement.ap.gov.in/historyofdisasters.aspx

5.2.5 LOSS ESTIMATES DUE TO 2000-DEPRESSION IN ANDHRA PRADESH

A well-marked low pressure area developed over the Bay of Bengal on 22nd August 2000. On the following day, the system became a depression located about 150 km south-southeast of Visakhapatnam, Andhra Pradesh. Moving westward, the system soon moved ashore near Kakinada without intensifying beyond winds of 45 km/h and quickly weakened into a remnant low on 24th August 2000.

While moving ashore, the depression produced torrential rainfall across Andhra Pradesh. The capital city of Hyderabad recorded 240 mm of rainfall on 24th August. During the last week of August, the state recorded the highest precipitation in 46 years, which overflowed lakes and flooded several towns. Severity of the flood caused by the 2000 event is shown in the photographs in Figure 5-28.

Figure 5-28: Flood damage photographs associated with the 2000 Flooding in Andhra Pradesh

Details of loss estimates due to rainfall induced flooding for this event in the study area for Residential, Commercial and Industrial buildings are given in Table 5-49. The table shows highest estimated residential building losses of INR 30.32 crores in Srikakulam and INR 30.07 crores in East Godavari. The table also highlights highest estimated commercial building losses of INR 1.42 crores for East Godavari and INR 1.11 crores for Srikakulam. The table indicates that residential and industrial building losses contribute higher flood losses as compared to the commercial building losses. Residential, Commercial, and Industrial building losses contribute about 82%, 5%, and 13% losses respectively to the combined structural losses.

Table 5-49: Loss estimates of cyclone induced rainfall flood due to 2000-Depression in Andhra Pradesh

Sl. No.	Affected Districts	Losses (INR crores)			
		Residential	Commercial	Industrial	Combined Losses
1	East Godavari	30.07	1.42	8.96	40.45
2	Guntur	2.69	0.12	-	2.81
3	Krishna	1.04	0.09	0.01	1.14
4	Prakasam	6.32	0.33	0.90	7.55
5	Sri Potti Sriramulu Nellore	5.86	0.25	0.70	6.81
6	Srikakulam	30.32	1.11	1.80	33.23
7	Vishakhapatnam	4.56	0.95	0.88	6.39
8	Vizianagaram	0.09	-	-	0.09
9	West Godavari	0.24	0.01	0.01	0.26

Sl. No.	Affected Districts	Losses (INR crores)			
		Residential	Commercial	Industrial	Combined Losses
Grand Total		**81.19**	**4.27**	**13.26**	**98.73**

Details of the affected districts, number of affected villages, households, and population are given in Table 5-50. The table shows that East Godavari was the worst affected district in Andhra Pradesh by cyclone induced rainfall flooding due to the 2000 depression with highest affected population, affected villages, and affected households.

Table 5-50: Vulnerable population and households due to 2000-Depression in Andhra Pradesh

Sl. No.	Affected Districts	Number of Affected Villages	Number of Affected Households	Affected Population	Affected Population (%)
1	East Godavari	91	14,770	53,289	22%
2	Guntur	30	1,989	7,656	5%
3	Krishna	19	1,161	4,235	6%
4	Prakasam	22	3,457	13,768	15%
5	Sri Potti Sriramulu Nellore	74	3,389	12,788	9%
6	Srikakulam	63	5,974	20,491	10%
7	Vishakhapatnam	24	2,232	5,678	8%
8	Vizianagaram	2	23	119	12%
9	West Godavari	10	203	730	1%
Grand Total		335	33,198	118,755	12%

Details of the vulnerable infrastructure asset classes, public utilities, and essential facilities due to 2000 depression are summarized in Table 5-51 and Table 5-52. The associated estimated losses of these vulnerable exposure classes due to 2000 depression are given in Table 5-53. Roads contribute highest losses of INR 72.78 crores (32%) followed by schools, which contribute INR 72.07 crores (31%) to the total losses of public utilities and infrastructure due to the 2000 depression in Andhra Pradesh. Agriculture crops losses of about INR 411 crores have been estimated for this event.

Table 5-51: Affected public utilities and infrastructure due to 2000-Depression in Andhra Pradesh

District	Bridges	Admin HQ	Police Stations
East Godavari	32	2	3
Guntur	10	1	-
Krishna	2		-
Prakasam	16		1
Nellore	19		-
Srikakulam	10		-
Vishakhapatnam	12	1	-
Vizianagaram	4		-
West Godavari	6	-	-
Grand Total	111	4	4

Table 5-52: Affected essential facilities and religious places due to 2000-Depression in Andhra Pradesh

District	Schools			Hospitals			Cyclone Shelters			Religious Places		
	Damage <1 %	Damage 1% - 5%	Damage >5%	Damage <1 %	Damage 1% - 5%	Damage >5%	Damage <1 %	Damage 1% - 5%	Damage >5%	Damage <1 %	Damage 1% - 5%	Damage >5%
East Godavari	41	308	201	15	127	109	-	3	9	-	68	63
Guntur	117	52	39	37	15	12	-	2	2	-	12	15
Krishna	73	8	52	24	5	18	-	-	3	3	6	26
Prakasam	34	56	0	17	25	0		6	-	-	25	1

District	Schools			Hospitals			Cyclone Shelters			Religious Places		
	Damage <1 %	Damage 1% - 5%	Damage >5%	Damage <1 %	Damage 1% - 5%	Damage >5%	Damage <1 %	Damage 1% - 5%	Damage >5%	Damage <1 %	Damage 1% - 5%	Damage >5%
Nellore	100	71	10	52	27	4	-	8	1	1	46	8
Srikakulam	62	140	2	33	64	1		-	-	-	66	4
Vishakhapatnam	16	80	0	10	49	0	-	-	-	-	37	2
Vizianagaram	1	9	0	0	1	0		-	-	-	13	2
West Godavari	1	2	30	1	0	11			2	-	7	28
Grand Total	445	726	334	189	313	155	0	19	17	4	280	149

Table 5-53: Affected public utilities, essential facilities and infrastructure losses due to 2000-Depression in Andhra Pradesh

District	Losses (INR crores)														
	Schools	Hospitals	Airports	Bridges	Electric Lines	Oil and Gas	Portable Water	Railway Lines	Roads	Sea Ports	Waste Water	Religious Places	Admin Headquarters	Cyclone Shelters	Police Stations
East Godavari	11.32	1.42	-	53.06	0.12	2.67	4.28	15.37	50.27	-	3.47	1.34	0.14	0.09	0.02
Guntur	1.78	0.09	-	6.86	0.01	-	0.73	2.79	5.44	-	0.66	0.28	0.04	0.83	-
Krishna	1.78	0.3	-	3.89	0.01	-	0.45	-	4.31	-	0.47	0.24	0	0.24	-
Prakasam	0.99	0.1	-	1.71	0.01	-	0.2	4.27	4.04	-	0.12	0.13	-	0.04	0.01
Nellore	1.53	0.16	-	2.8	0.02	-	0.89	4.53	5.15	3.5	0.44	0.23	-	0.1	-
Srikakulam	2.87	0.35	-	0.63	0.01	-	0.1	1.17	1.37	-	0.09	0.15	-	-	-
Vishakhapatnam	1.99	0.42	4.45	0.15	0.01	-	0.12	0.19	0.68	0.12	0.1	0.07	0.02	-	-

District	Losses (INR crores)														
	Schools	Hospitals	Airports	Bridges	Electric Lines	Oil and Gas	Portable Water	Railway Lines	Roads	Sea Ports	Waste Water	Religious Places	Admin Headquarters	Cyclone Shelters	Police Stations
Vizianagaram	0.18	0.01	-	0.37	-	-	0.01	-	0.15	-	0.01	0.01	-	-	-
West Godavari	1.8	0.02	-	2.6	-	0.13	0.39	1.36	1.37	-	0.27	0.16	-	0.03	-
Grand Total	24.24	2.87	4.45	72.07	0.19	2.8	7.17	29.68	72.78	3.62	5.63	2.61	0.2	1.33	0.03

The residential, commercial, and industrial building losses at village-level due to the 2000-depression are shown in Figure 5-29, Figure 5-30 and Figure 5-31 respectively.

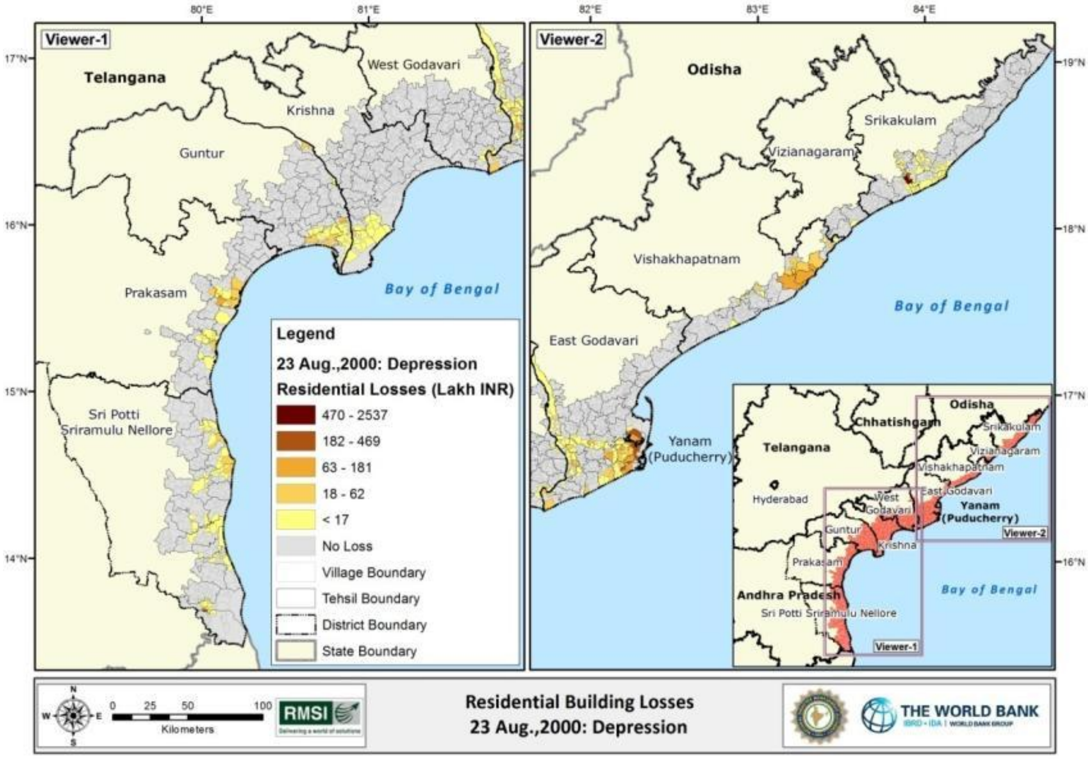

Figure 5-29: Estimated losses for cyclone induced rainfall flood due to 2000-Depression for Residential Buildings

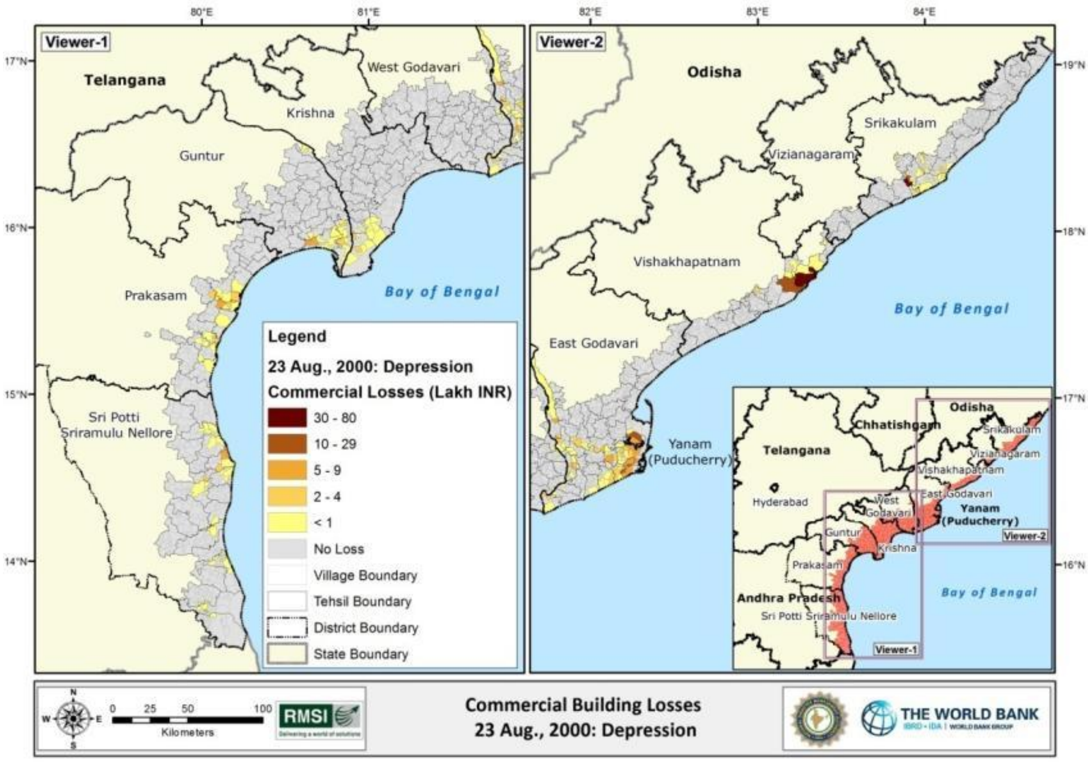

Figure 5-30: Estimated losses for cyclone induced rainfall flood due to 2000-Depression for Commercial Buildings

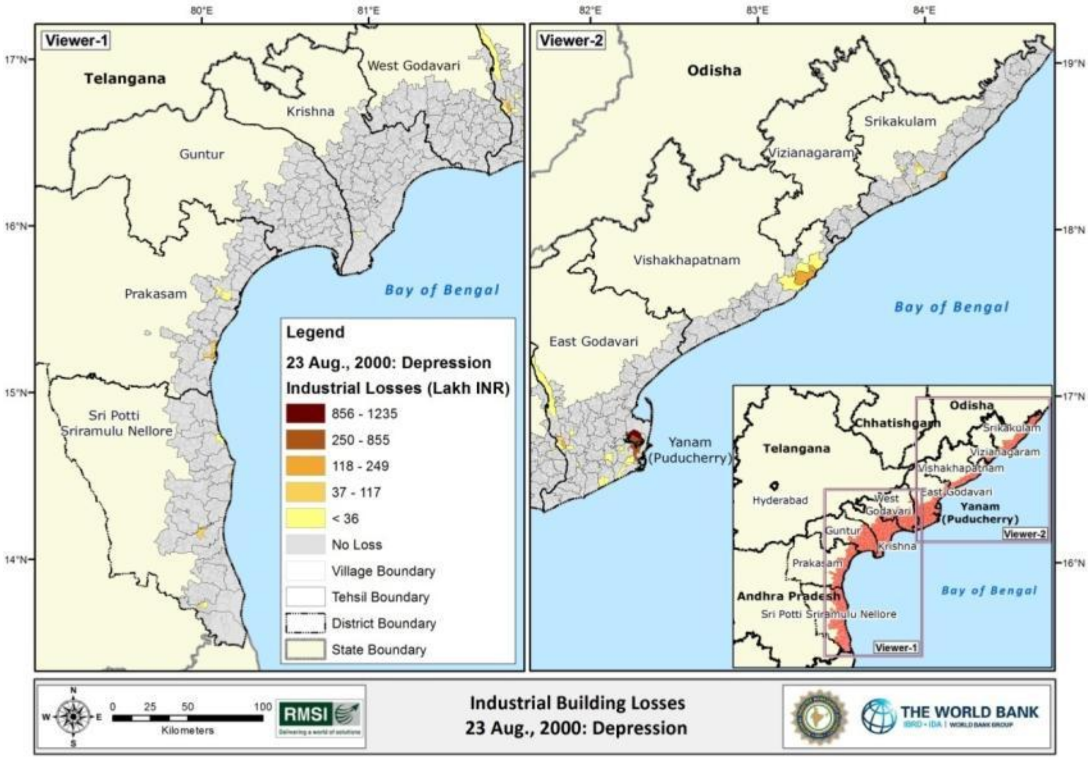

Figure 5-31: Estimated losses for cyclone induced rainfall flood due to 2000-Depression for Industrial Buildings

The losses due to cyclonic wind and storm surge have not been reported for this event as there were no significant contributions due to these hazards. The detailed comparison between reported and estimated losses is given below.

5.2.5.1 Loss validation for 2000-depression

The 2000-depression produced torrential rainfall across Andhra Pradesh. The rains followed flooding in Srikakulam and East Godavari districts of Andhra Pradesh. A comparison between estimated and reported losses from various available sources has been given in Table 5-54. The losses have been estimated for nine districts of Andhra Pradesh for the event, while 19 districts have been considered in the losses reported in available sources. Hence, considering this, a variation is observed when estimated losses are compared with reported losses for the same event. These estimated losses are on the lower side as the study was limited up to 10-m elevation from coastline.

Table 5-54: Loss validation for 2000-Depression

S. No.	Exposure Type	Reported (RDM, Govt of AP)	Estimated
1	Number of District Affected	17	9
2	Population Affected	198,364	118,755
3	Households Damaged	99,800	33,198
4	Estimated Losses (Crore)	966	740

5.3 Shelter Need Assessment

As the cyclone warnings have become very effective in India in recent times, safe shelters play a very important role in protecting and saving life. The cyclone shelters are generally located:

- on high grounds, above ocean storm tide inundation levels and river or creek flood levels
- near the evacuating community and directly accessible from a public roadway
- away from other potential hazards, such as tall structures and trees or places storing fuel or hazardous materials

The cyclone shelter's structure differs from normal buildings as it is designed to withstand more severe wind pressure and wind borne debris caused by wind gusts of super cyclones. Though all coastal states of India have constructed cyclone shelters, their capacity is not adequate and local administrations have to resort to using schools, community centers, and religious buildings as cyclone-flood shelters.

As per NDMA guidelines, the shelter capacity is assessed based on space required for a person to stand. As per this, the shelters constructed in Andhra Pradesh and Odisha with areas around 2,000-3,000 sq. ft have an estimated capacity for 2,000-3,000 people. However, for our analysis, we have considered minimum space for a person to lie down and have included schools, community centers, and religious places besides cyclone and flood shelters.

The capacity of the shelter buildings is assessed against the potential affected population to derive the shelter needs. We have carried out this exercise at village level – the lowest administrative unit considering the minimum distance people have to commute as well as the availability of data. For schools, we have considered the number of rooms assuming that each room can accommodate 25 people. For religious centers, we do not have accurate information of safe built up areas and have considered 50 persons per religious building. This is based on assumptions made during field observations considering an average size. For potentially affected population, we have considered people living in all kutcha and semi pucca houses besides taking into account historical damages. The shelter gaps at village level for both the states are presented in section 6.5.

The limitation of this exercise is that there is not enough information on the safety status of schools and religious places.

5.4 Hotspot Analysis

Hotspot analysis was carried out in both the states to identify villages/urban areas, which need priority intervention towards cyclone risk mitigation. For hotspot analysis, we considered all aspects that impact the people, including the intensity of events in terms of wind speed, flood depth and surge height, vulnerability of the people, and the exposed elements. The exercise was carried out in GIS considering all these aspects using an index based approach. The steps followed are further detailed below and is further demonstrated below.

1. Compiled the average hazard values for flood, storm surge, and wind at village-level from the hazard grid map. Similarly, for exposure, the cluster-level data was converted to village-level and hazard and exposure index maps were generated.
2. Both hazard and exposure index maps were further grouped into high, medium, and low using 'natural break' method assigning value 1, 2, and 3 for low, moderate, and high hazard index, respectively. In the case of SoVI for which we have already developed ranking (for example, highly vulnerable villages are ranked 1 etc.), these rankings have been used in a cumulative manner along with the hazard and exposure indexes.
3. All villages with 'High' composite hazard index, 'High' Exposure index and 'High' Social vulnerability index were selected as hotspot villages/urban areas.
4. Prioritized hotspot villages further based on high hazard values, SoVI, and shelter needs, and numbered the hotspots.
5. For detailed field investigation, we suggest taking the top two hotspot villages/or wards from urban areas.

As the number of hotspot villages range from 33 in Odisha to 40 in Andhra Pradesh, we further tried to prioritize these hotspots using the highest values of hazard, exposure, SOVI, and shelter gaps. This exercise was required to identify top hotspot villages for carrying out further detailed investigations.

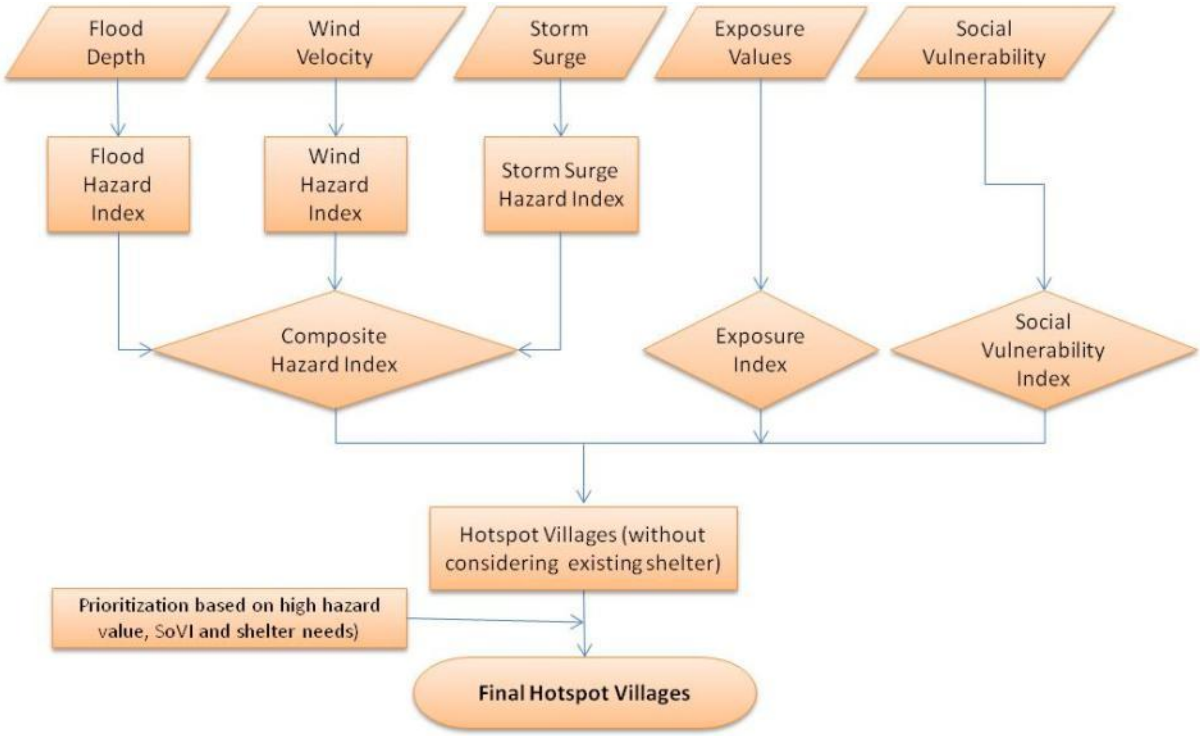

Figure 5-32: Steps followed for identification of hotspots

6 Key Findings

The methodology described in section 5 above was applied to all types of exposure elements for all return period scenarios as well as historical cyclones. Losses were first estimated based on wind, storm surge, and cyclonic rainfall induced flooding from various events. These individual losses were then combined to obtain the composite losses from wind, surge, and cyclonic rainfall induced flood. This section summarizes the losses from various scenarios and presents the key observations on cyclone risk from multiple perspectives. The section culminates with the identification of hot spots for the states of Odisha and Andhra Pradesh.

6.1 State Level Losses

This section presents state-level losses. Table 6-1 shows a summary of losses from various return period scenarios grouped by wind, surge, flood, and composite loss. Estimates of losses for various scenarios for three hazards are provided in Table 6-1 that presents the Probable Maximum Loss (PML) for general occupancy (Residential, Industrial, and Commercial) classes. PML is estimated for six key scenarios (2, 5, 10, 25, 50, and 100 years).

The table indicates that PML is insignificant for 2 and 5-year return periods for all three hazards. However, significant losses are estimated (259.48 Crores, 111.35 Crores, and 379.76 Crores) for Residential, Commercial, and Industrial buildings, respectively, corresponding to a 100-year return period scenario.

The Industrial losses have a higher contribution in composite losses followed by residential losses due to all three hazards in Andhra Pradesh. However, Residential sector followed by Commercial losses have higher contributions in composite losses for Odisha. The Table also depicts that losses due to cyclone induced flood hazard have a higher contribution to composite residential sector losses in both states. For Commercial and Industrial sector losses, losses due to flood hazard contribute more for lower return periods, whereas cyclonic wind hazard contributes more for higher return periods.

Table 6-1: State-level losses for various return periods for residential, commercial and industrial occupancy

Probabilistic Scenarios	Andhra Pradesh				Odisha			
Hazard Return Periods	Wind	Surge	Flood	Composite	Wind	Surge	Flood	Composite
Residential (Loss in INR Crores)								
2 Yr RP	31.57	1.49	59.87	67.70	8.83	0.40	60.59	61.24
5 Yr RP	54.82	1.79	97.96	112.27	26.03	0.62	108.03	111.12
10 Yr RP	103.86	2.17	115.44	155.30	64.41	0.90	135.60	150.12
25 Yr RP	451.07	2.64	151.11	475.72	180.72	14.36	170.81	249.08
50 Yr RP	1,137.98	3.63	200.15	1,155.46	362.01	38.84	194.66	412.86
100 Yr RP	2,571.56	16.80	258.93	2,584.62	675.74	123.39	217.37	720.49
Commercial (Loss in INR Crores)								
2 Yr RP	1.29	0.37	3.69	3.93	2.71	0.05	18.48	18.68
5 Yr RP	2.25	0.41	5.20	5.68	8.64	0.07	31.91	33.06
10 Yr RP	4.41	0.44	6.16	7.59	21.09	0.14	40.33	45.51
25 Yr RP	19.25	0.52	7.64	20.71	58.46	5.09	50.42	77.36
50 Yr RP	48.87	0.69	9.38	49.76	115.66	15.19	58.01	130.29
100 Yr RP	110.73	1.49	11.68	111.35	213.82	49.90	64.93	228.97
Industrial (Loss in INR Crores)								
2 Yr RP	2.52	0.95	7.95	8.39	2.35	16.48	41.56	44.76
5 Yr RP	4.35	1.07	16.17	16.78	7.30	20.73	110.33	112.50
10 Yr RP	8.06	1.18	21.52	23.01	18.28	26.83	129.95	133.94
25 Yr RP	34.85	1.45	21.64	41.05	51.85	70.24	154.42	177.40
50 Yr RP	87.44	2.36	30.96	92.79	104.93	116.20	167.18	229.04
100 Yr RP	196.34	9.19	39.21	200.42	197.20	212.90	183.35	343.26

6.2 Losses for Other Exposure Elements

This section presents state-level view losses by key exposure elements such as essential facilities, transportation network and utilities. Table 6-2 to Table 6-4 shows a summary of the losses to various key exposure elements from various return period scenarios grouped by wind, surge, flood, and composite loss.

The district-wise losses for all six scenarios for Andhra Pradesh and Odisha are given in Annex 1. The table depicts that Jagatsinghpur is the most vulnerable district of Odisha due to storm surge hazard in all three occupancy classes (Residential, Commercial, and Industrial). It is followed by Bhadrak district in Residential and Industrial occupancy classes, and Kendrapara in Commercial occupancy class. Nellore, Vishakhapatnam, and East Godavari districts are most vulnerable districts in Residential, Commercial and Industrial occupancy classes respectively in Andhra Pradesh.

Similarly, Jagatsinghpur is the most vulnerable district due to cyclonic wind hazard for all three occupancy types in Odisha. Nellore, Vishakhapatanam, and Krishna districts are most vulnerable districts in Residential, Commercial and Industrial occupancy classes respectively in Andhra Pradesh due to cyclonic wind.

Similarly, Jagatsinghpur is the most vulnerable district due to cyclone induced flood hazard for Residential and Industrial occupancy classes and Kendrapara is the most vulnerable district for Commercial occupancy class in Odisha. Srikakulam is the most vulnerable district due to cyclone induced flood hazard for Residential and Commercial occupancy classes whereas East Godavari is the most vulnerable district for Industrial occupancy class due to cyclone induced flooding in Andhra Pradesh.

Table 6-2: Scenario losses for various return periods for essential facilities

Probabilistic Scenarios	Andhra Pradesh				Odisha			
Return Periods	Wind	Surge	Flood	Composite	Wind	Surge	Flood	Composite
Schools (Loss in INR Crores)								
2 Yr RP	1.29	1.87	13.76	13.94	2.69	6.25	70.38	70.71
5 Yr RP	1.29	1.93	17.58	17.73	4.73	6.53	85.33	85.71
10 Yr RP	1.37	2.02	20.38	20.52	12.64	9.22	103.46	104.64
25 Yr RP	6.80	2.53	21.71	22.89	36.07	12.36	125.45	131.12
50 Yr RP	17.74	3.17	26.65	32.17	71.31	26.52	145.30	164.02
100 Yr RP	40.05	5.00	32.37	51.74	130.62	58.10	165.60	218.77
Hospitals (Loss in INR Crores)								
2 Yr RP	0.23	0.11	1.08	1.11	0.40	0.15	0.09	0.64
5 Yr RP	0.26	0.13	1.53	1.55	0.79	0.49	0.12	1.07
10 Yr RP	0.31	0.17	1.83	1.87	1.18	0.72	0.13	1.53
25 Yr RP	1.02	0.21	1.99	2.24	3.42	0.96	0.15	3.69
50 Yr RP	2.47	0.25	2.40	3.46	6.91	1.38	0.16	7.35
100 Yr RP	5.42	0.41	3.02	6.22	12.85	2.52	0.18	12.85
Fire Stations (Loss in INR Crores)								
2 Yr RP	0.19	-	-	0.19	0.55	-	0.28	0.62
5 Yr RP	0.19	-	-	0.19	0.94	-	0.42	1.03
10 Yr RP	0.20	-	0.99	1.01	2.58	-	0.55	2.64
25 Yr RP	0.95	-	1.37	1.67	7.02	-	0.65	7.05

Probabilistic Scenarios	Andhra Pradesh				Odisha			
Return Periods	Wind	Surge	Flood	Composite	Wind	Surge	Flood	Composite
Schools (Loss in INR Crores)								
50 Yr RP	2.34	-	1.65	2.86	13.64	-	0.73	13.66
100 Yr RP	5.14	-	2.78	5.85	25.47	-	0.78	25.48

Table 6-3: Scenario losses for various return periods for transportation networks

Probabilistic Scenarios	Andhra Pradesh				Odisha			
Return Periods	Wind	Surge	Flood	Composite	Wind	Surge	Flood	Composite
Roads (Loss in INR Crores)								
2 Yr RP	-	1.80	21.98	22.05	-	0.26	12.91	12.91
5 Yr RP	-	2.16	25.42	25.51	-	0.47	18.73	18.73
10 Yr RP	-	2.71	29.82	29.94	-	0.65	26.22	26.22
25 Yr RP	-	3.76	36.47	36.66	-	3.59	33.07	33.26
50 Yr RP	-	5.50	43.15	43.50	-	15.11	40.24	42.98
100 Yr RP	-	7.26	46.52	47.09		53.63	43.22	68.88
Airports (Loss in INR Crores)								
2 Yr RP	-	-	7.83	7.83	-	-	-	-
5 Yr RP	-	-	7.83	7.83	-	-	-	-
10 Yr RP	-	-	7.83	7.83	0.95	-	-	0.95
25 Yr RP	10.49	-	7.83	13.09	5.64	-	-	5.64
50 Yr RP	21.77	-	8.17	23.25	8.29	-	-	8.29
100 Yr RP	50.87	-	9.02	51.66	15.44	-	-	15.44
Seaports (Loss in INR Crores)								
2 Yr RP	-	4.30	-	4.30	-	0.14	-	0.14
5 Yr RP	-	4.31	-	4.31	0.56	0.29	1.16	1.32
10 Yr RP	0.12	4.45	-	4.45	1.35	0.36	2.24	2.64
25 Yr RP	2.42	5.51	-	6.02	4.08	1.41	3.14	5.34
50 Yr RP	5.81	8.42	-	10.23	8.29	5.59	3.16	10.49
100 Yr RP	13.14	17.42	-	21.82	16.29	18.24	3.23	24.67

Table 6-4: Scenario losses for various return periods for utilities

Probabilistic Scenarios	Andhra Pradesh				Odisha			
Return Periods	Wind	Surge	Flood	Composite	Wind	Surge	Flood	Composite
Communication Systems (Loss in INR Crores)								
2 Yr RP	0.58	0.21	-	0.62	0.37	0.14	-	0.40
5 Yr RP	0.58	0.23	-	0.62	0.83	0.18	-	0.85
10 Yr RP	0.93	0.21	-	0.95	1.94	0.23	-	1.95
25 Yr RP	3.49	0.30	-	3.50	5.15	0.39	-	5.17
50 Yr RP	8.72	0.42	-	8.73	10.06	0.77	-	10.09
100 Yr RP	19.66	0.65	-	19.67	18.32	1.76	-	18.41
Potable Water (Loss in INR Crores)								
2 Yr RP	-	-	0.62	0.62	-	-	0.02	0.02
5 Yr RP	-	-	0.66	0.66	-	-	0.03	0.03
10 Yr RP	-	-	0.75	0.75	-	-	0.04	0.04
25 Yr RP	-	-	0.69	0.69	-	-	0.05	0.05
50 Yr RP	-	-	0.81	0.81	-	-	0.06	0.06
100 Yr RP	49.07	-	1.11	49.08	17.64	-	0.07	17.64
Waste Water (Loss in INR Crores)								
2 Yr RP	-	-	0.68	0.68	-	-	0.03	0.03
5 Yr RP	-	-	0.62	0.62	-	-	0.04	0.04
10 Yr RP	-	-	0.68	0.68	-	-	0.05	0.05
25 Yr RP	-	-	0.72	0.72	-	-	0.06	0.06
50 Yr RP	-	-	0.77	0.77	-	-	0.07	0.07
100 Yr RP	8.45	-	0.86	8.49	13.10	-	0.09	13.11

6.3 Loss Maps for Andhra Pradesh

This section presents PML (Probable Maximum Loss) maps for residential, commercial, and industrial occupancy classes for key return period scenarios pertaining to the three hazards considered, namely cyclonic wind, storm surge, and cyclone induced rainfall flood. As stated above, it may be noted that the PML for 2 and 5-year return periods for all three hazards are insignificant when compared to PML for higher return periods.

6.3.1 PML Maps for Cyclonic Wind

The residential, commercial, and industrial building losses for various scenarios (10, 50, and 100 year return periods) for Andhra Pradesh are given from Figure 6-1 to Figure 6-9. The residential loss maps depict that coastal areas of Sri Potti Sriramulu Nellore, East Godavari, and Visakhapatnam districts are more likely to be affected as compared to other districts. The losses in Sri Potti Sriramulu Nellore and East Godavari are mainly driven by the cyclonic wind hazard, as these areas are severely affected due to strong winds associated with cyclone. The coastal areas of Visakhapatnam district are likely to be affected more as this district has more commercial and industrial exposure near the coast.

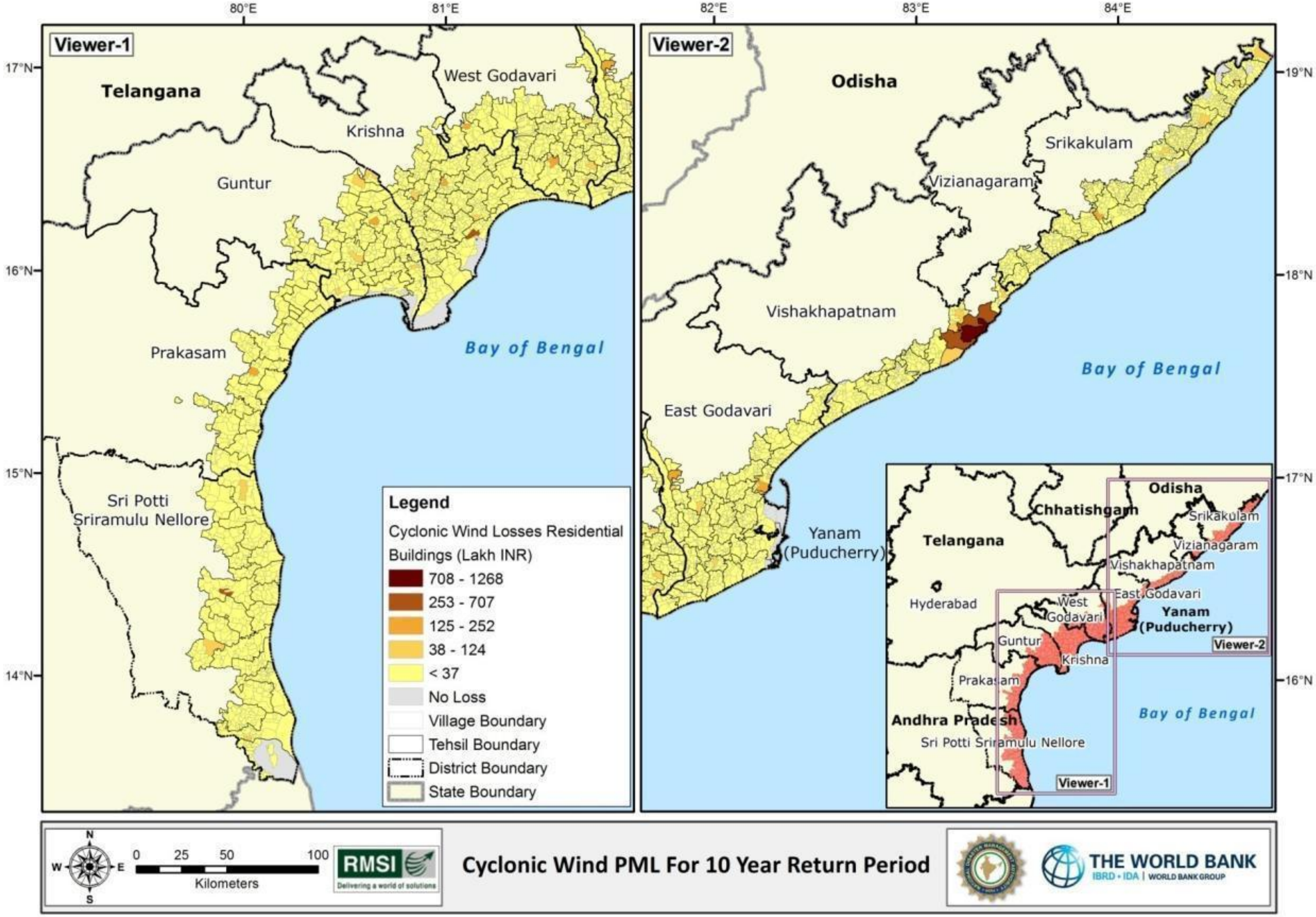

Figure 6-1: PML of residential buildings due to cyclonic wind for a 10-year return period scenario, Andhra Pradesh

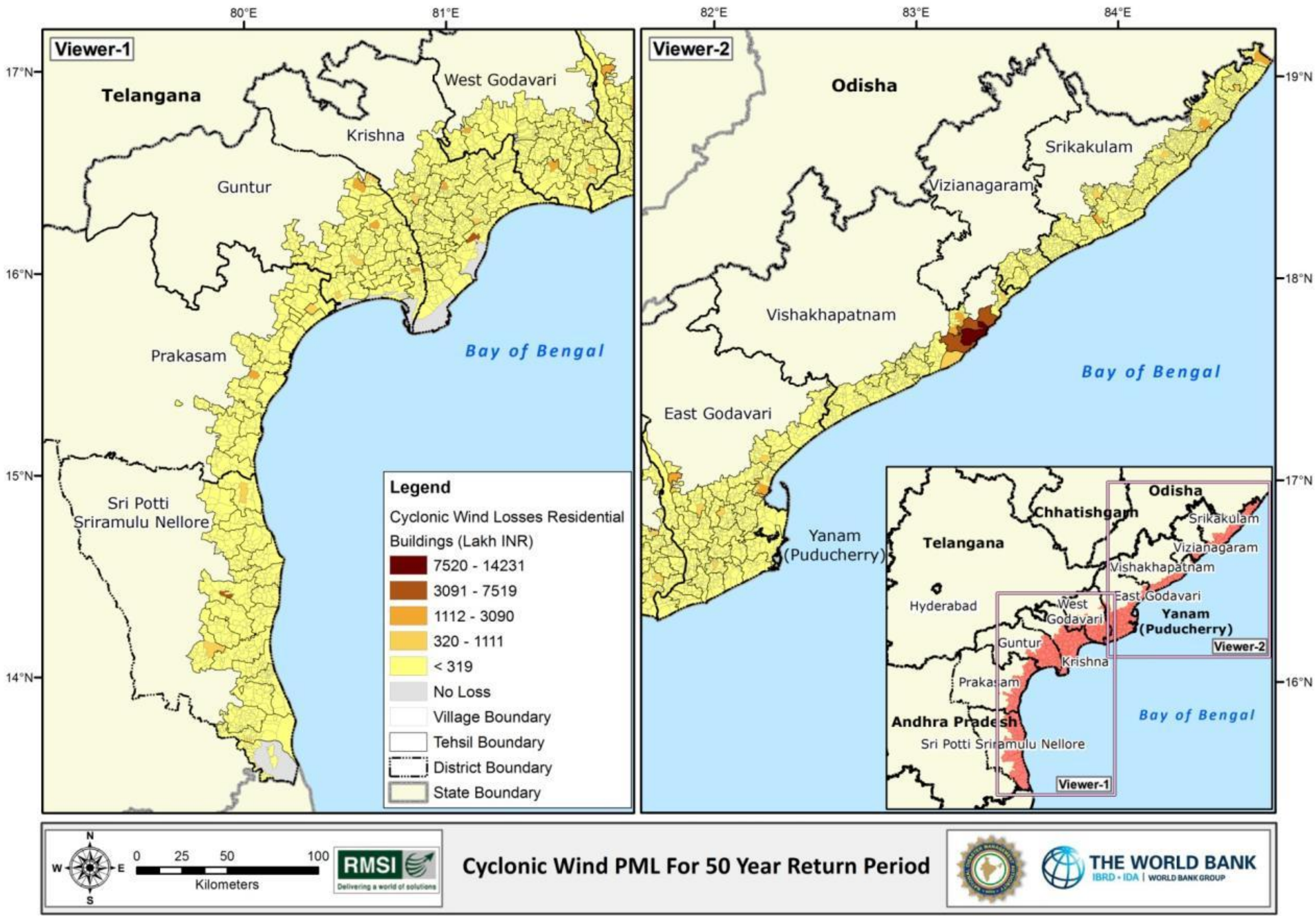

Figure 6-2: PML of residential buildings due to cyclonic wind for a 50-year return period scenario, Andhra Pradesh

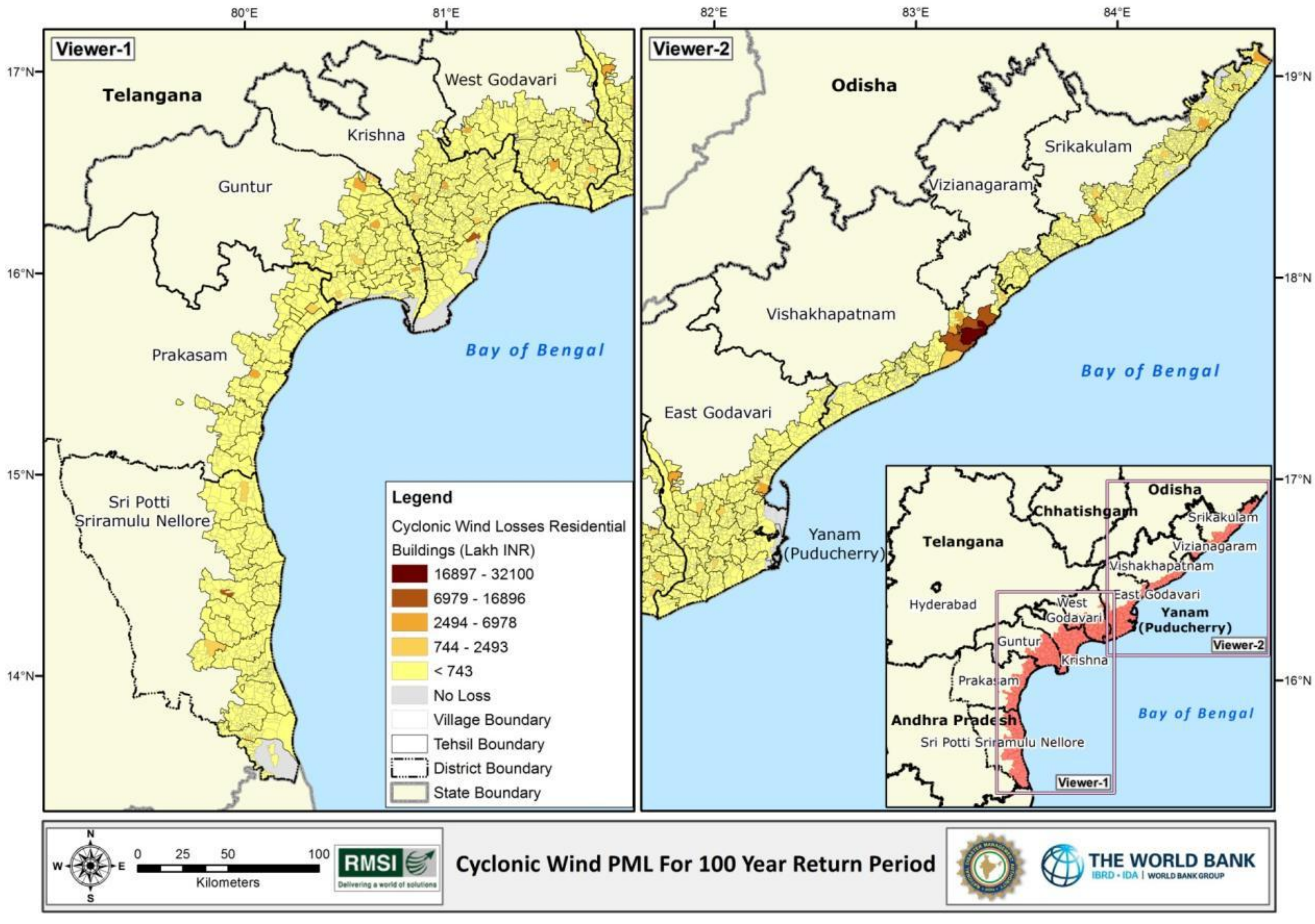

Figure 6-3: PML of residential buildings due to cyclonic wind for a 100-year return period scenario, Andhra Pradesh

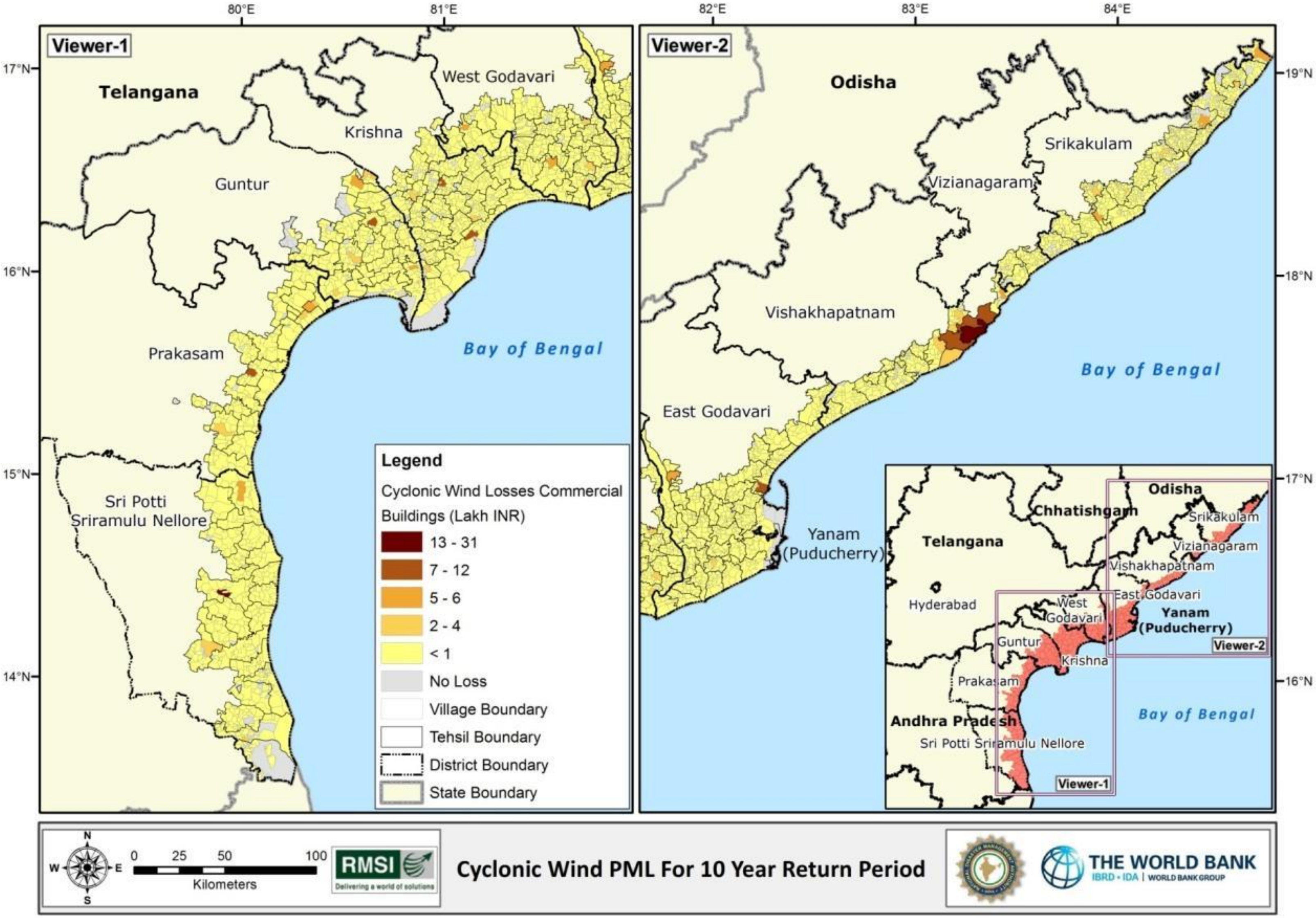

Figure 6-4: PML of commercial buildings due to cyclonic wind for a 10-year return period scenario, Andhra Pradesh

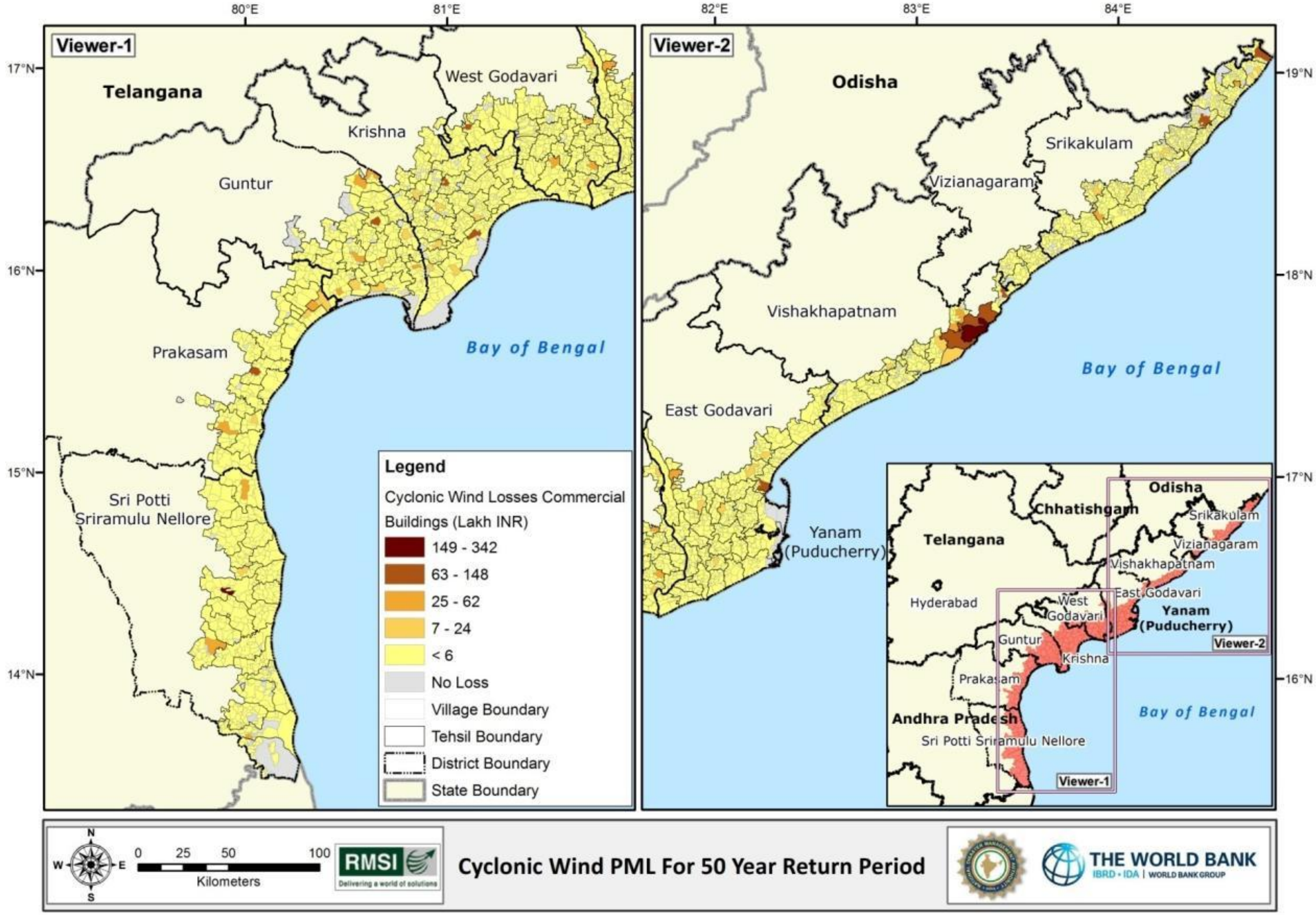

Figure 6-5: PML of commercial buildings due to cyclonic wind for a 50-year return period scenario, Andhra Pradesh

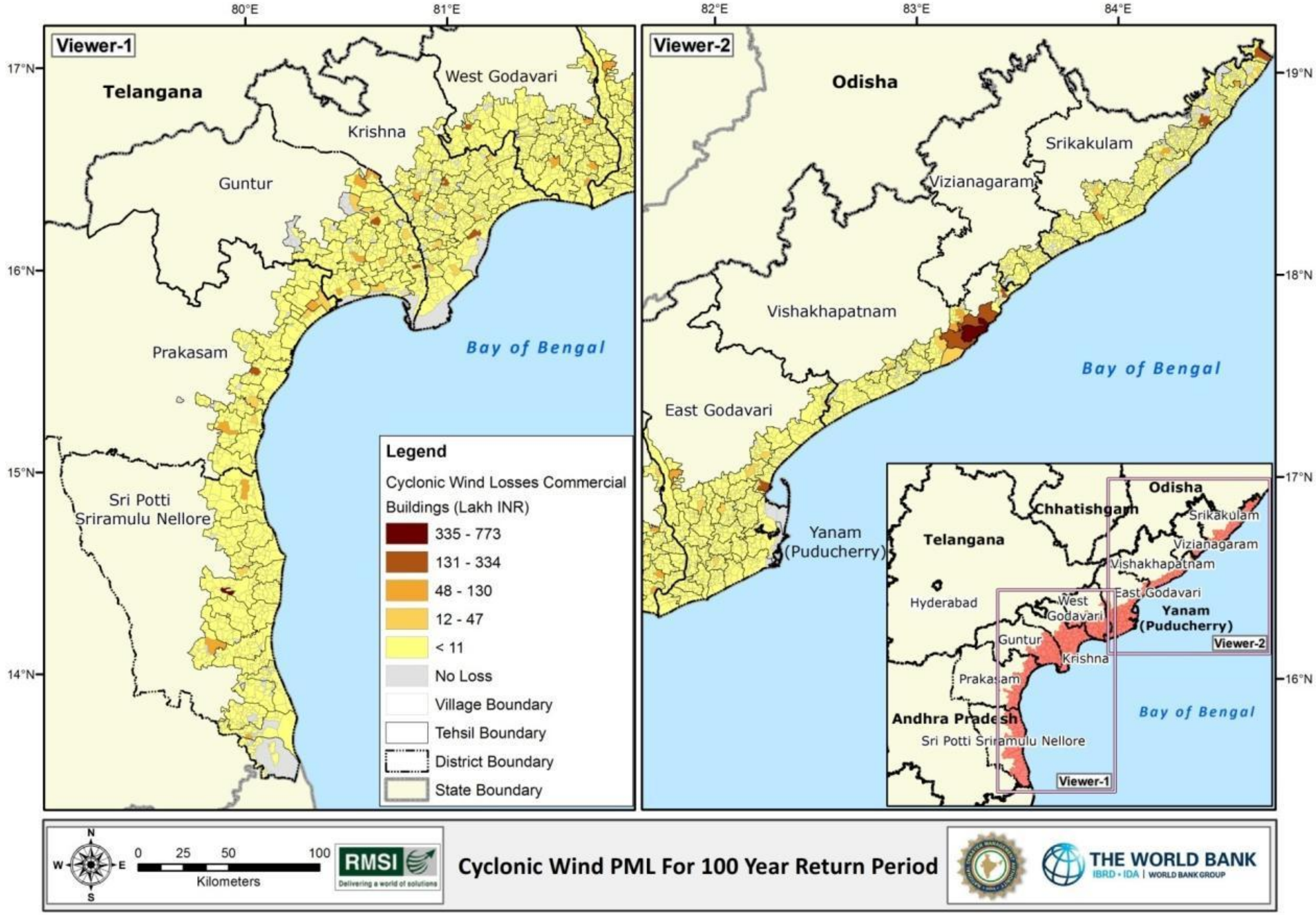

Figure 6-6: PML of commercial buildings due to cyclonic wind for a 100-year return period scenario, Andhra Pradesh

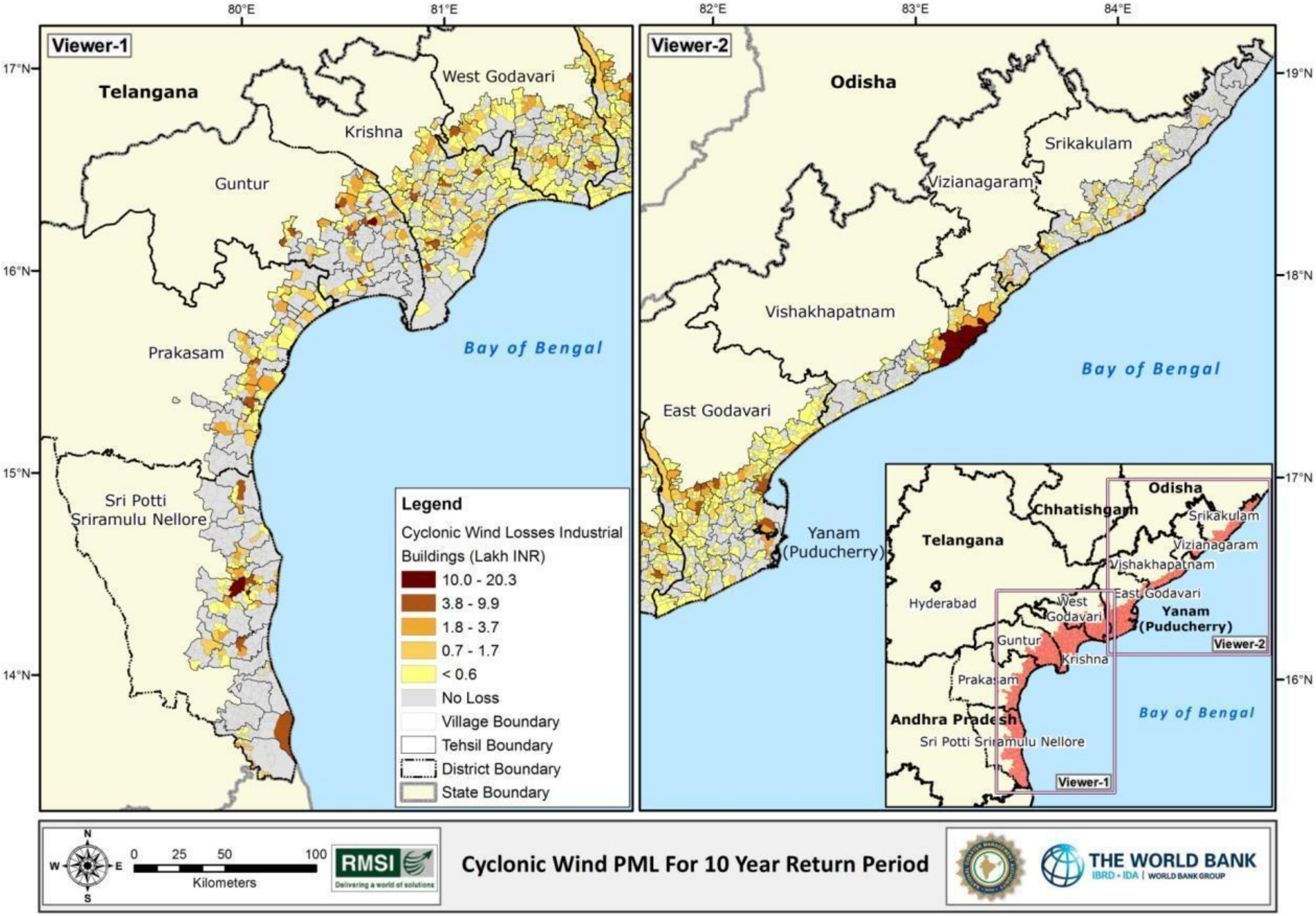

Figure 6-7: PML of industrial buildings due to cyclonic wind for a 10-year return period scenario, Andhra Pradesh

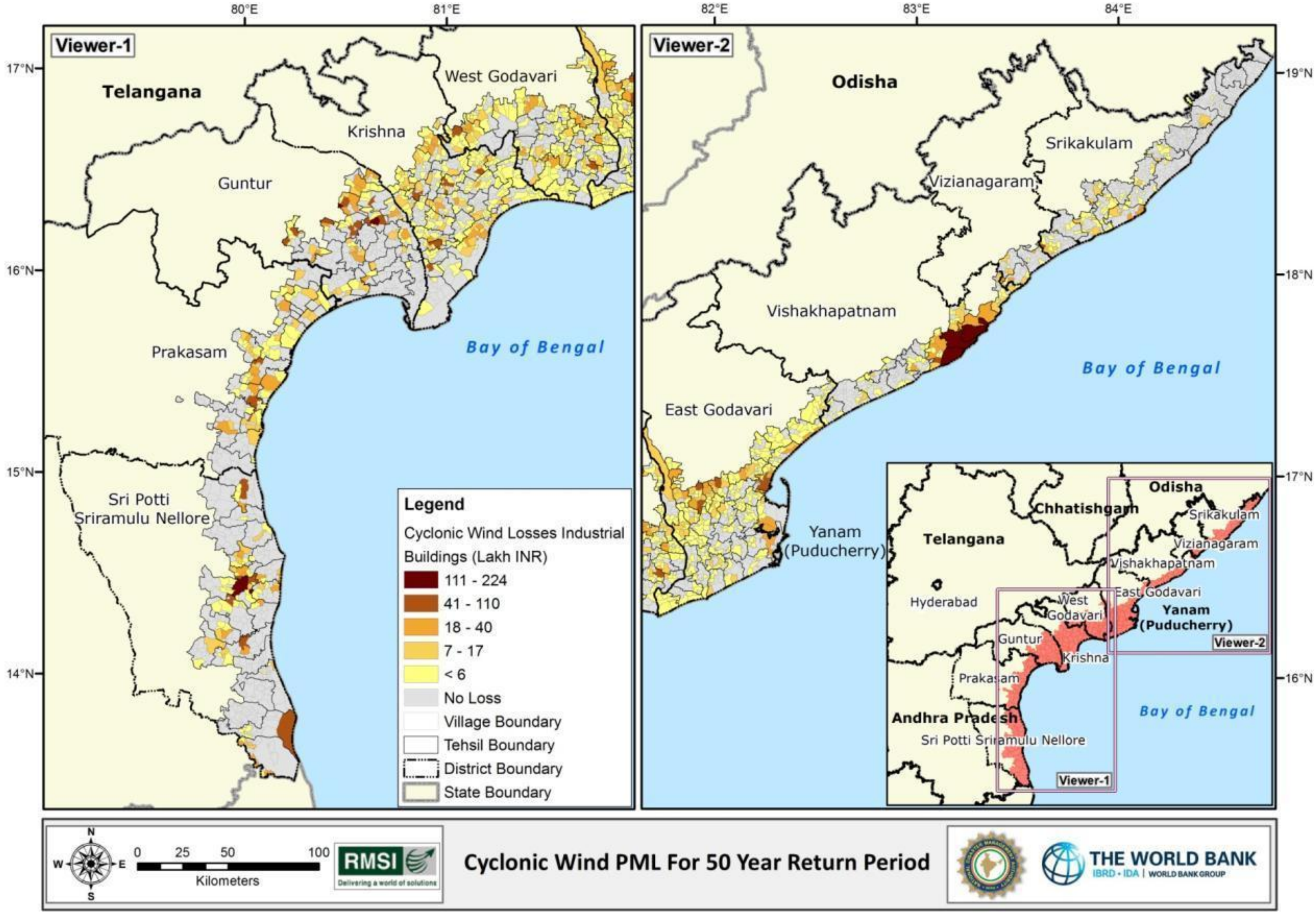

Figure 6-8: PML of Industrial buildings due to cyclonic wind for a 50-year return period scenario, Andhra Pradesh

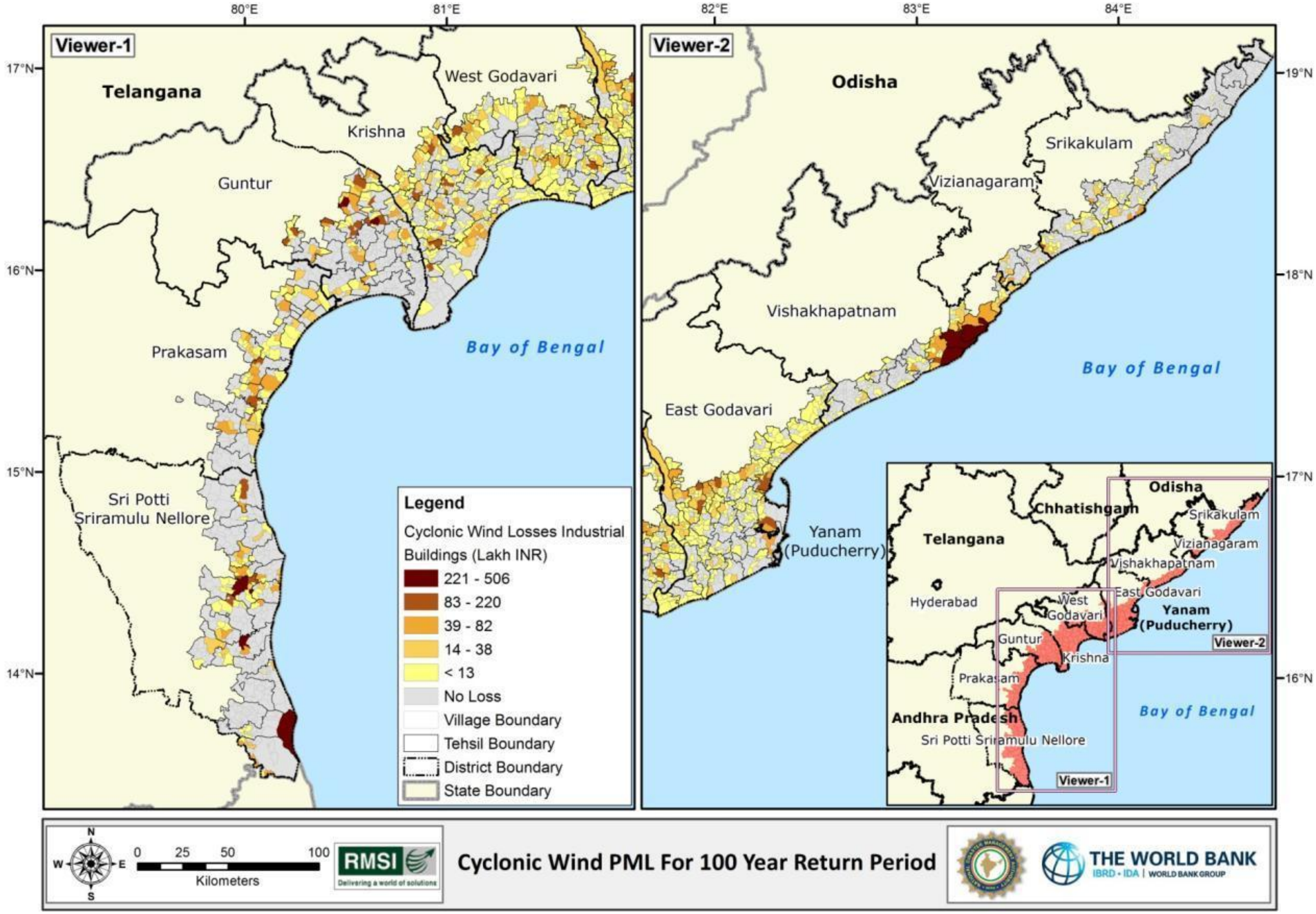

Figure 6-9: PML of industrial buildings due to cyclonic wind for a 100-year return period scenario, Andhra Pradesh

6.3.2 PML Maps for Storm Surge

The residential, commercial, and industrial building losses for various scenarios (10, 50, and 100 year return periods) for Andhra Pradesh are given from Figure 6-10 to Figure 6-18. The residential loss maps depict that coastal areas of Sri Potti Sriramulu Nellore, East Godavari, and Visakhapatnam districts are more likely to be affected as compared to other districts. The losses in Sri Potti Sriramulu Nellore and East Godavari are mainly driven by storm surge, as these areas are severely affected due to storm surge flooding. The coastal areas of Visakhapatnam district are likely to be affected more as this district has more commercial and Industrial exposure near the coast.

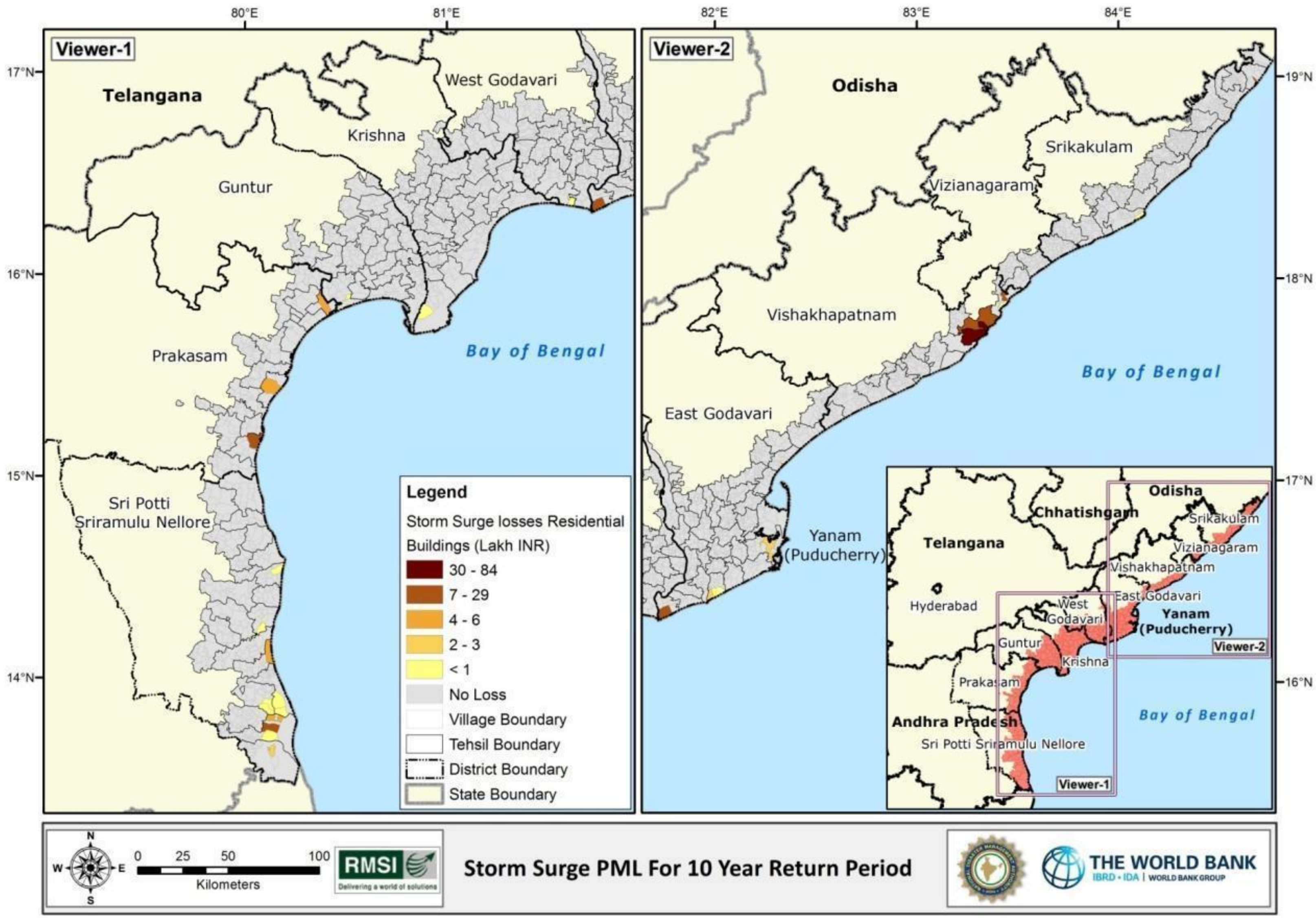

Figure 6-10: PML of residential buildings due to storm surge for a 10-year return period scenario, Andhra Pradesh

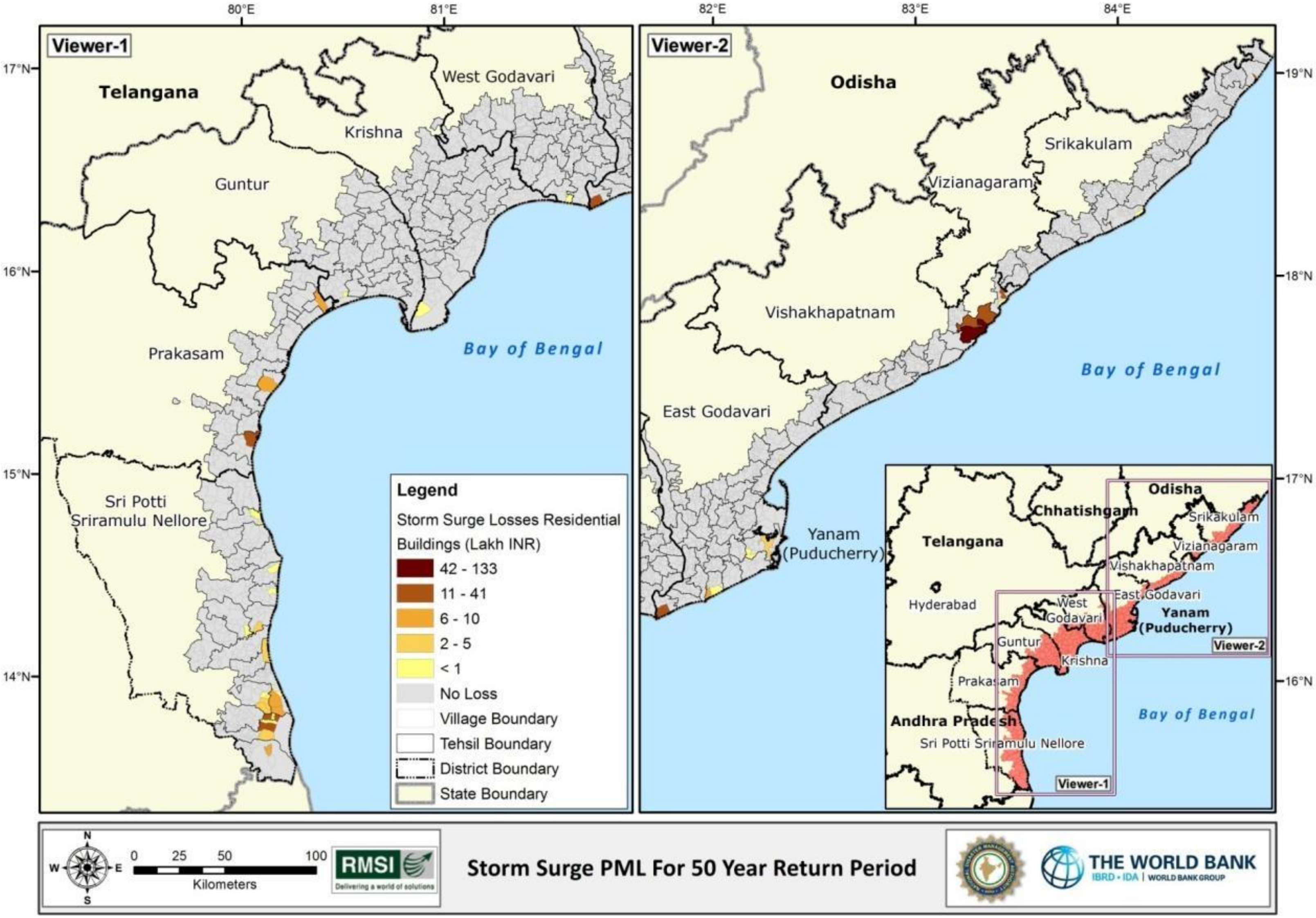

Figure 6-11: PML of residential buildings due to storm surge for a 50-year return period scenario, Andhra Pradesh

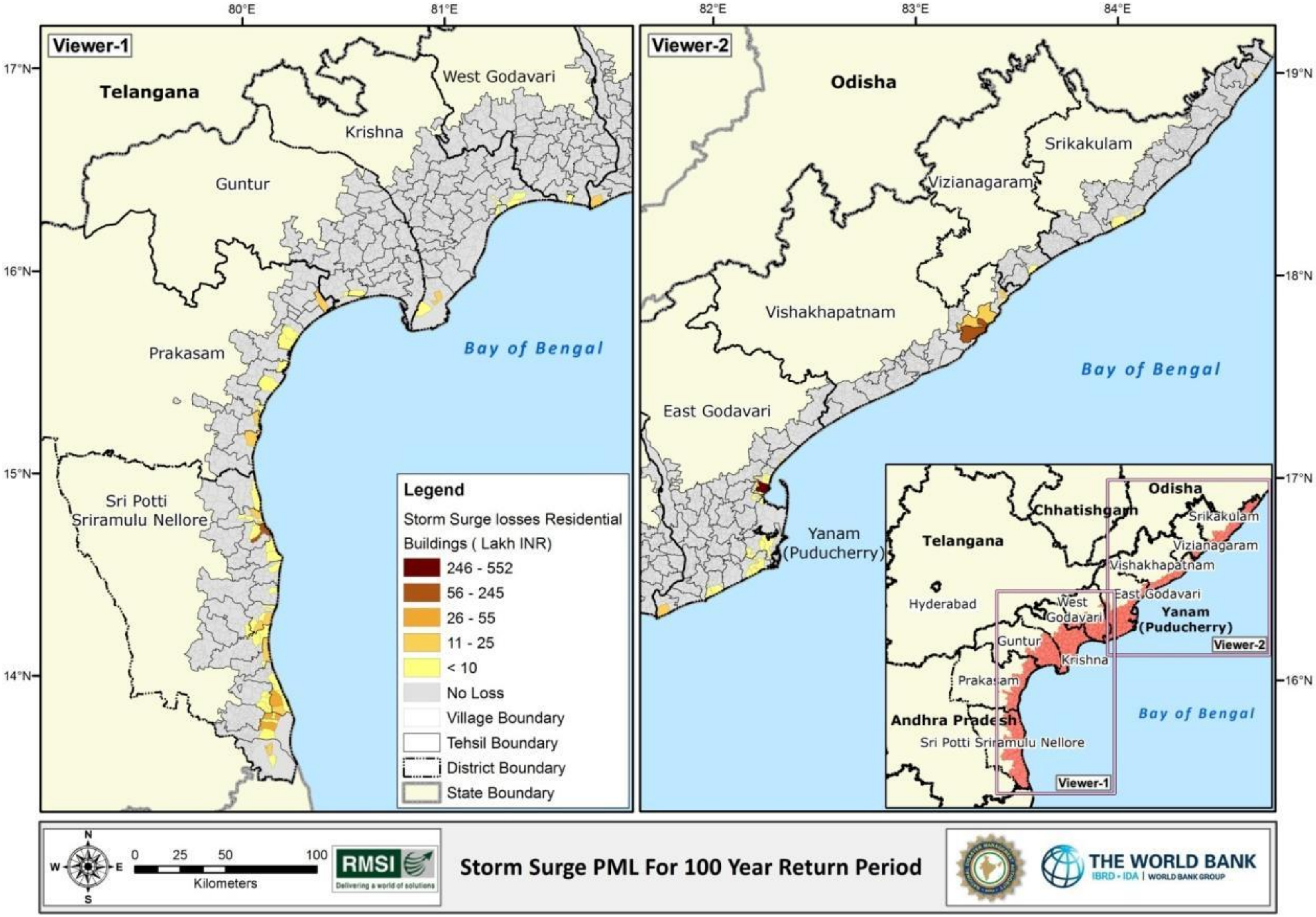

Figure 6-12: PML of residential buildings due to storm surge for a 100-year return period scenario, Andhra Pradesh

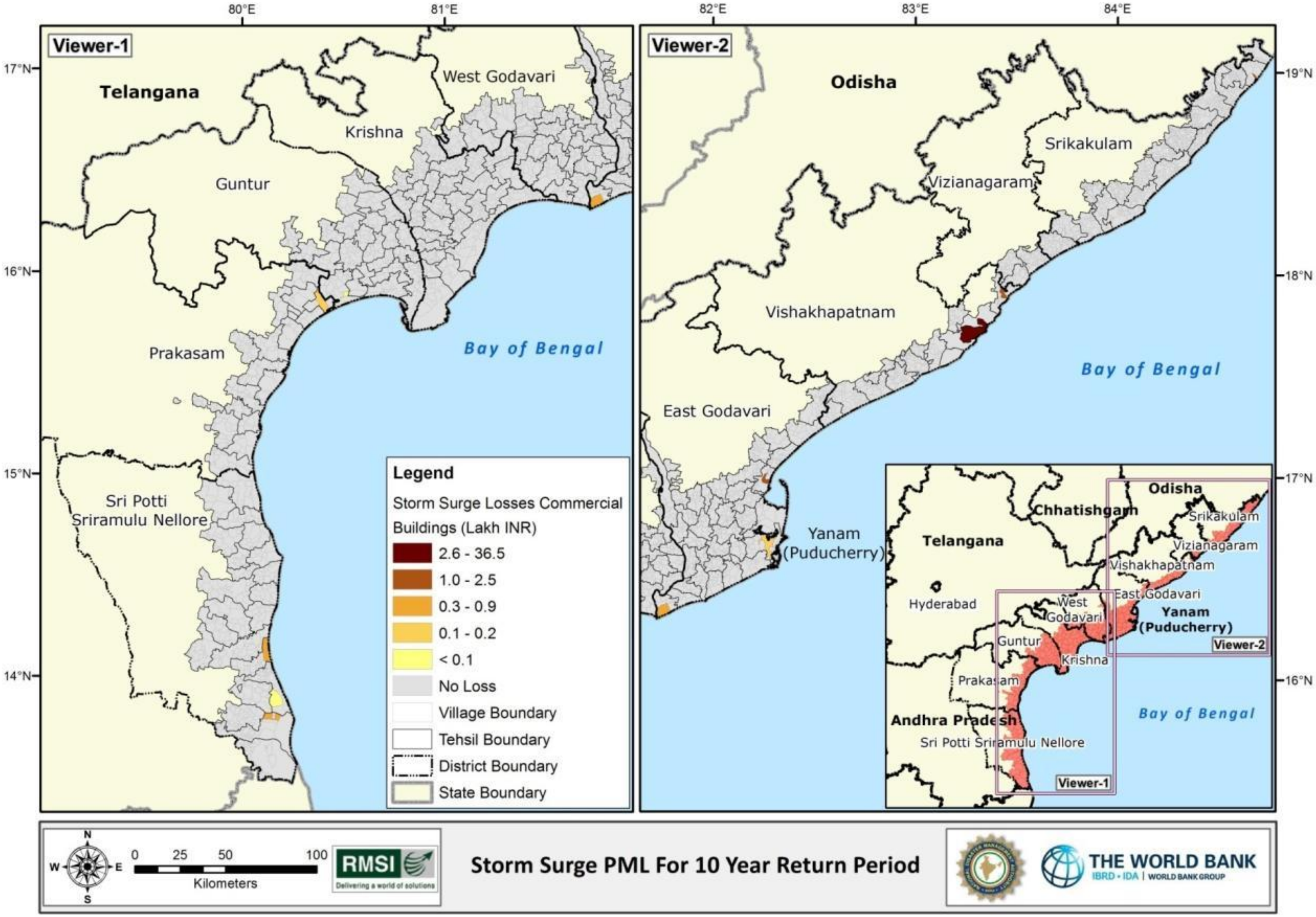

Figure 6-13: PML of commercial buildings due to storm surge for a 10-year return period scenario, Andhra Pradesh

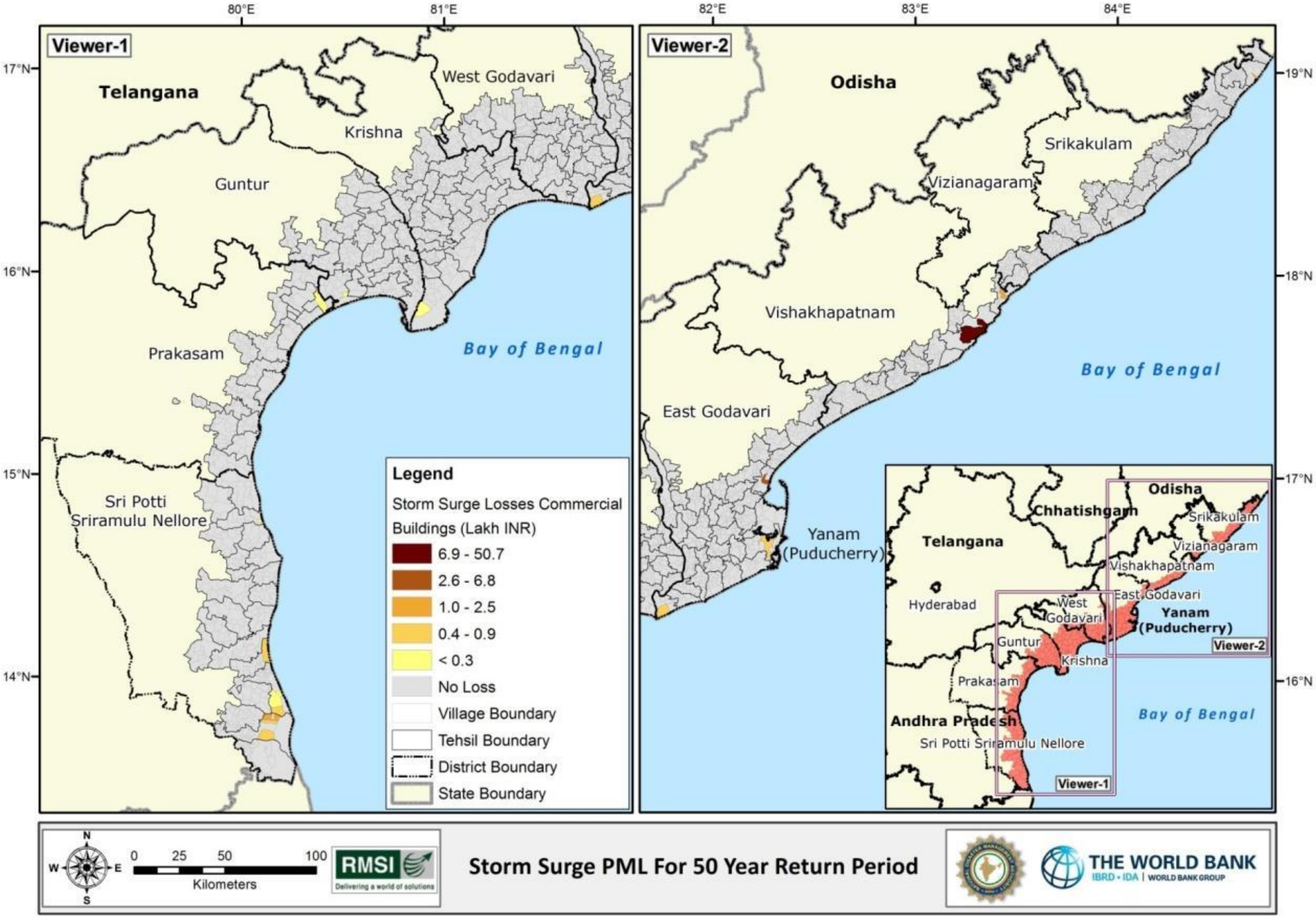

Figure 6-14: PML of commercial buildings due to storm surge for a 50-year return period scenario, Andhra Pradesh

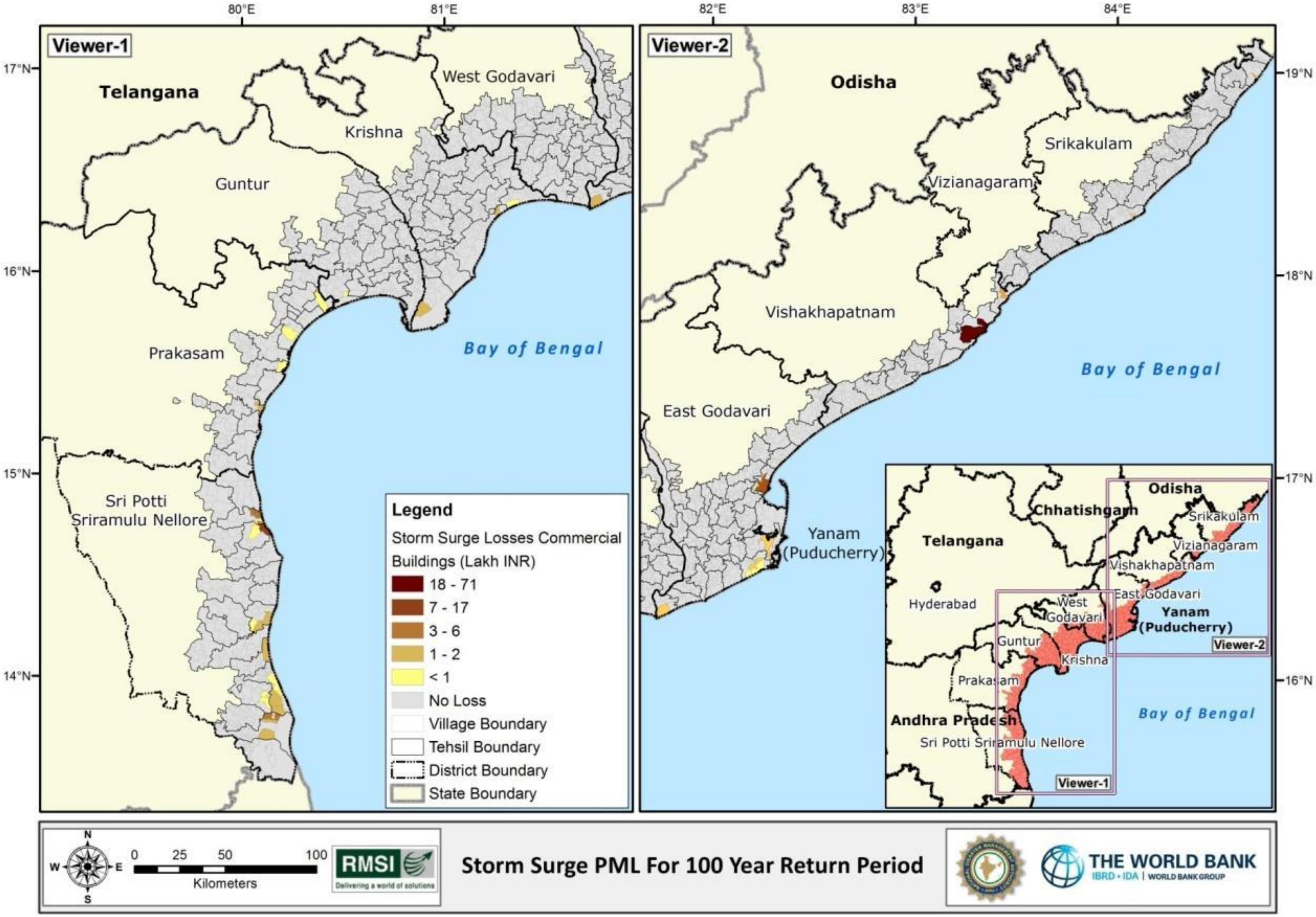

Figure 6-15: PML of commercial buildings due to storm surge for a 100-year return period scenario, Andhra Pradesh

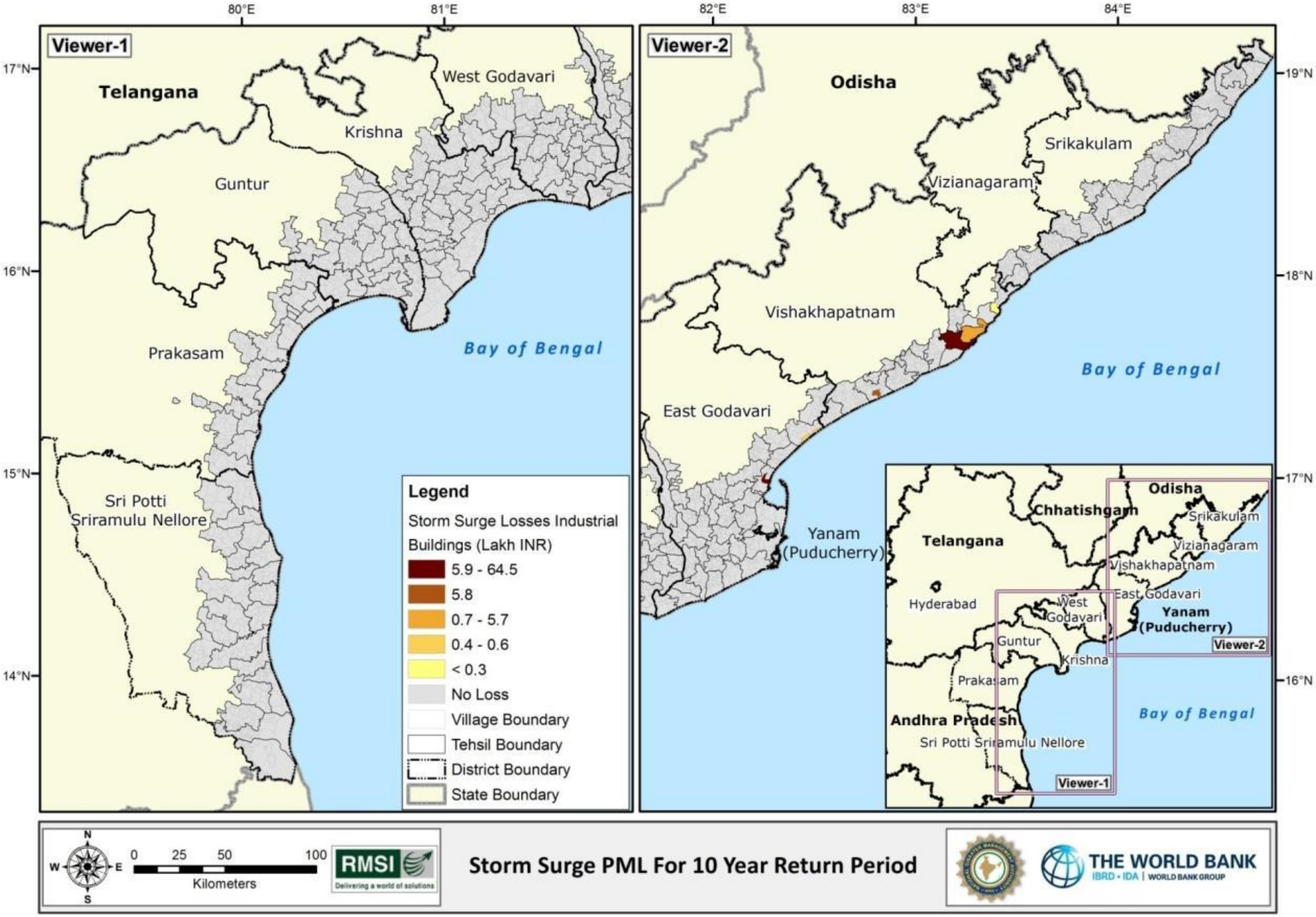

Figure 6-16: PML of industrial buildings due to storm surge for a 10-year return period scenario, Andhra Pradesh

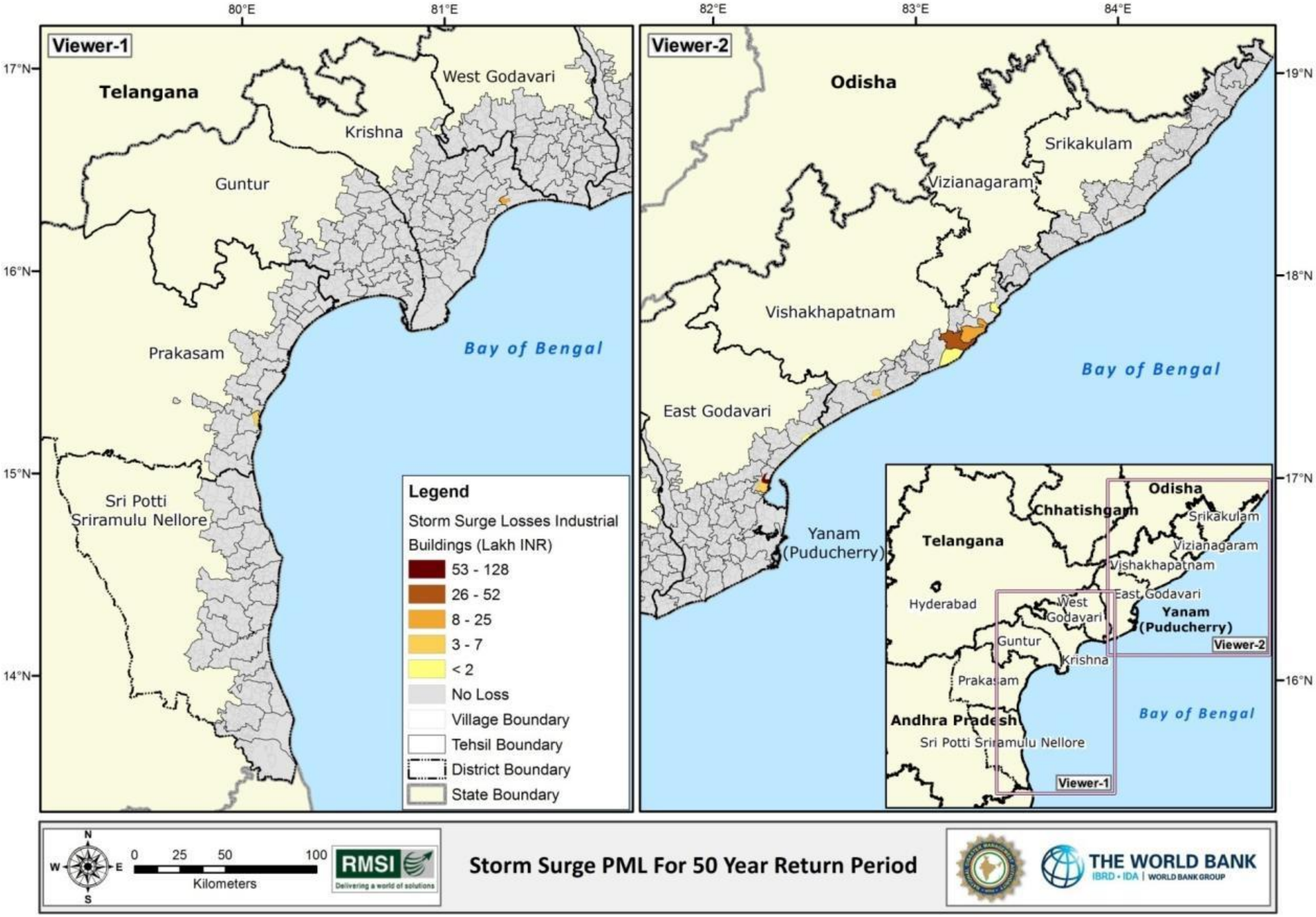

Figure 6-17: PML of industrial buildings due to storm surge for a 50-year return period scenario, Andhra Pradesh

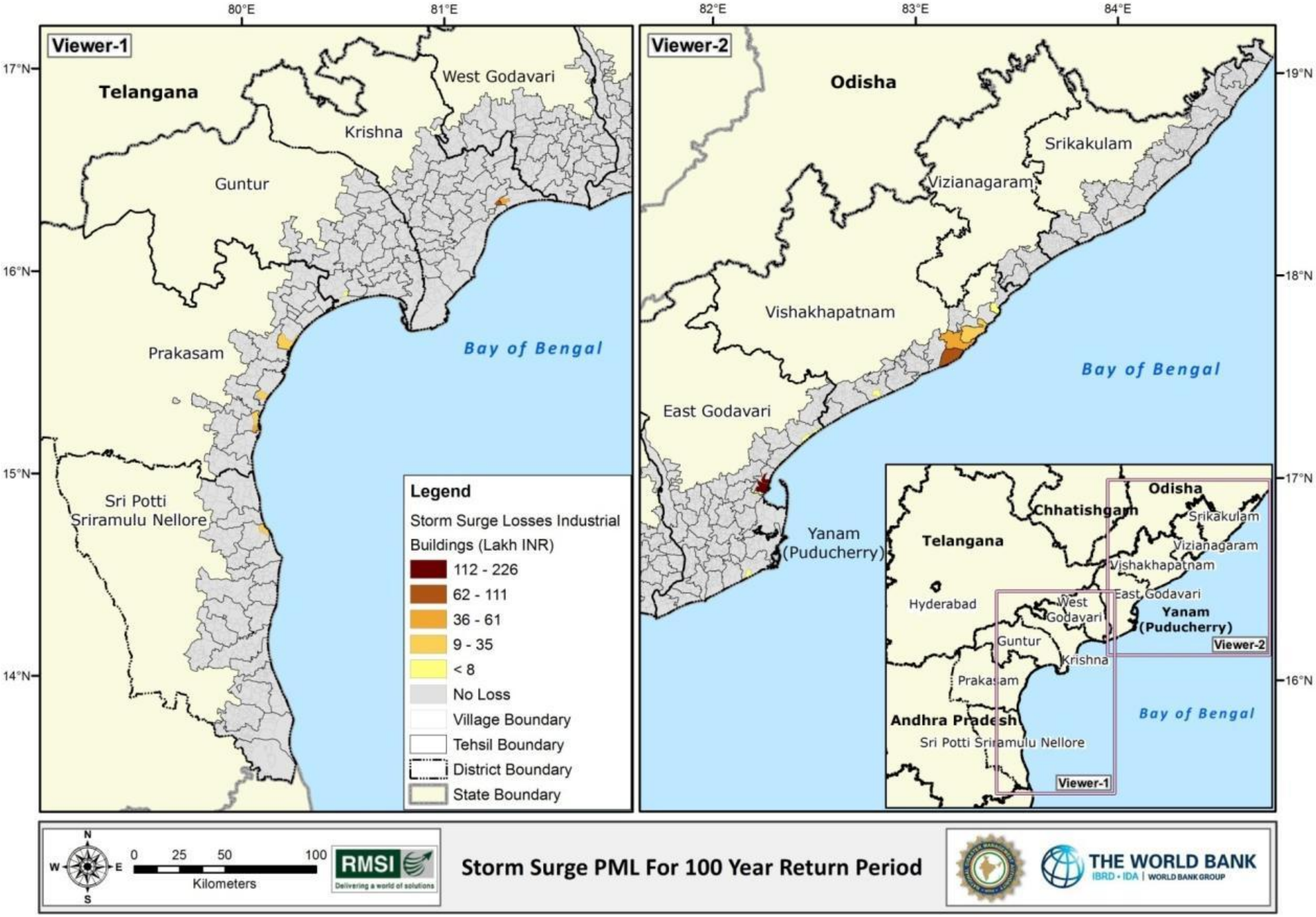

Figure 6-18: PML of industrial buildings due to storm surge for a 100-year return period scenario, Andhra Pradesh

6.3.3 PML Maps for Cyclone Induced rainfall Flood

The residential, commercial, and industrial building losses for various scenarios (10, 50, and 100 year return periods) for Andhra Pradesh are given from Figure 6-19 to Figure 6-27. The residential loss maps depict that coastal areas of Srikakulam, Visakhapatnam, Krishna, and East Godavari districts are more likely to be affected as compared to other districts. The losses in Srikakulam and East Godavari are mainly driven by cyclone induced rainfall flood, as these areas are severely affected due to cyclone induced flooding. The coastal areas of Visakhapatnam district are likely to be affected more as this district has more commercial and Industrial exposure near the coast.

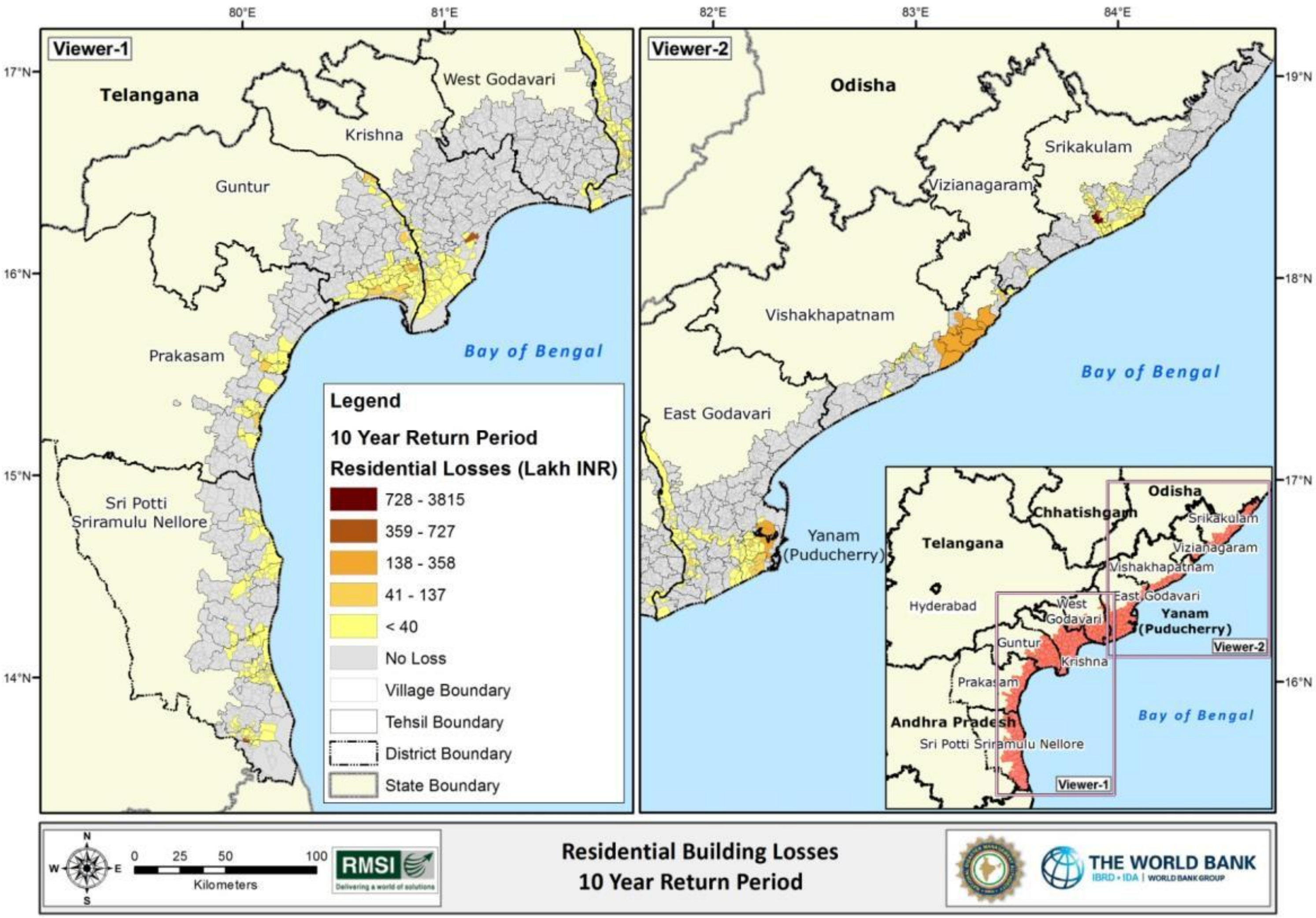

Figure 6-19: PML of residential buildings due to cyclonic rainfall induced flood for a 10-year return period scenario, Andhra Pradesh

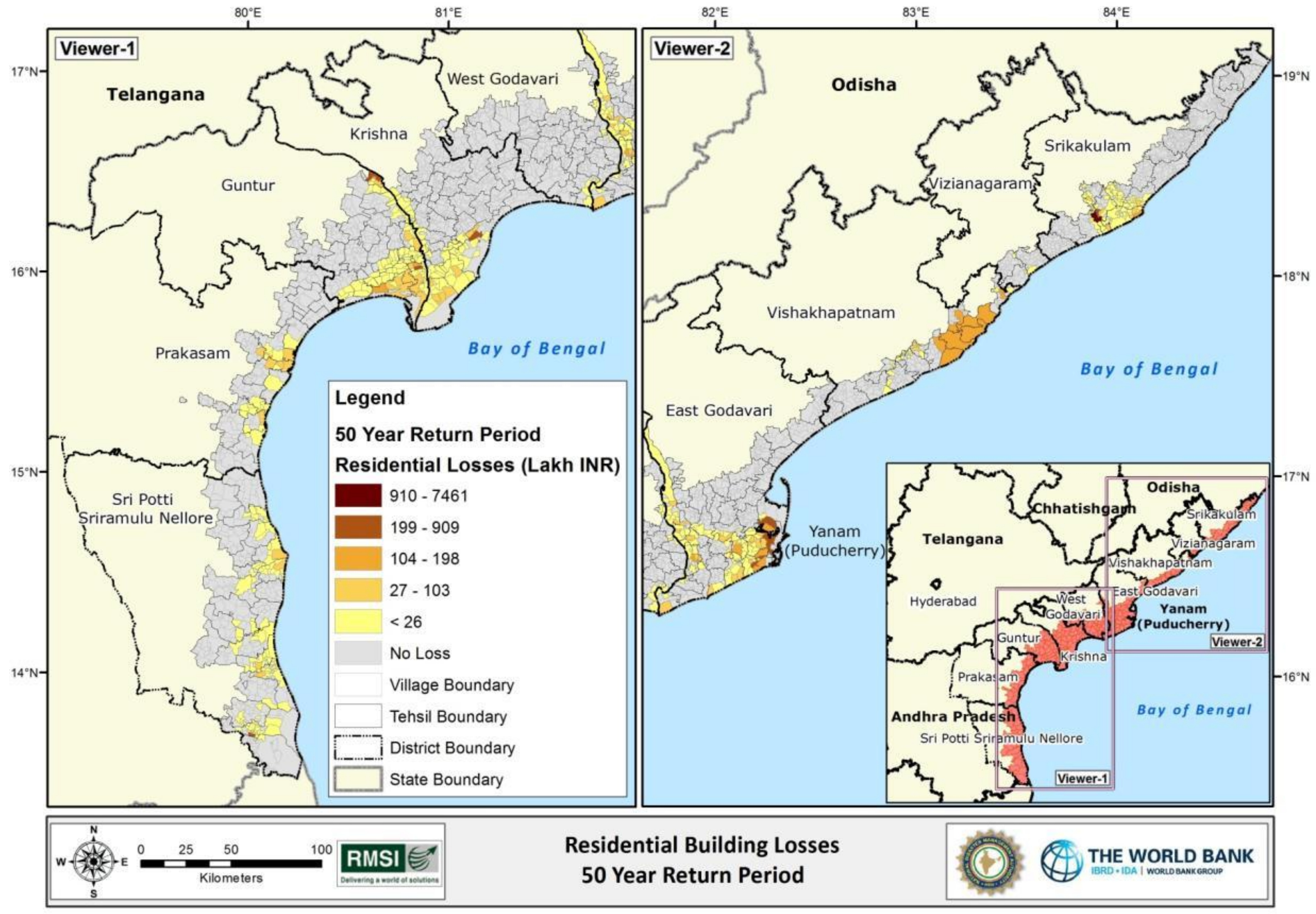

Figure 6-20: PML of residential buildings due to cyclonic rainfall induced flood for a 50-year return period scenario, Andhra Pradesh

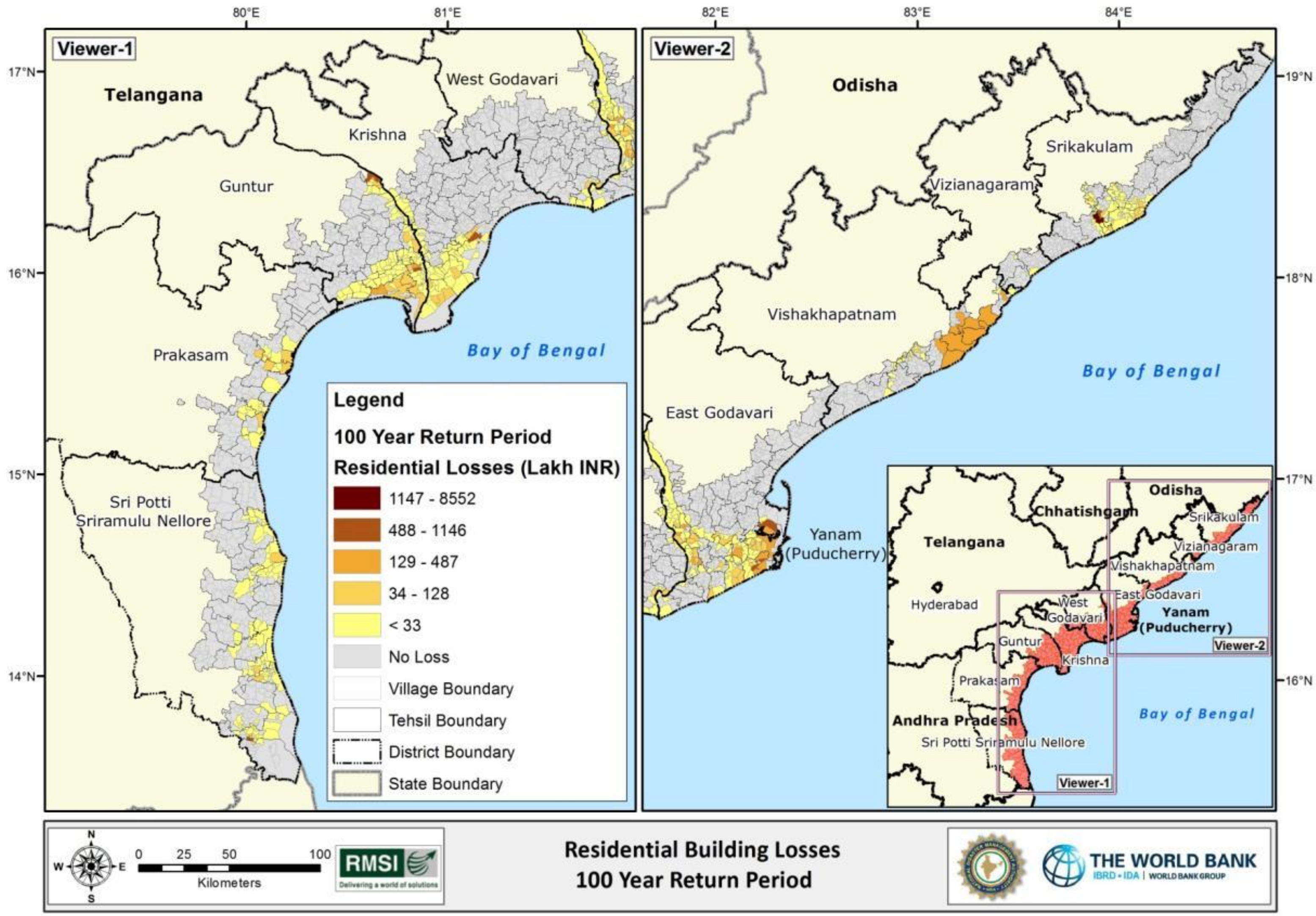

Figure 6-21: PML of residential buildings due to cyclonic rainfall induced flood for a 100-year return period scenario, Andhra Pradesh

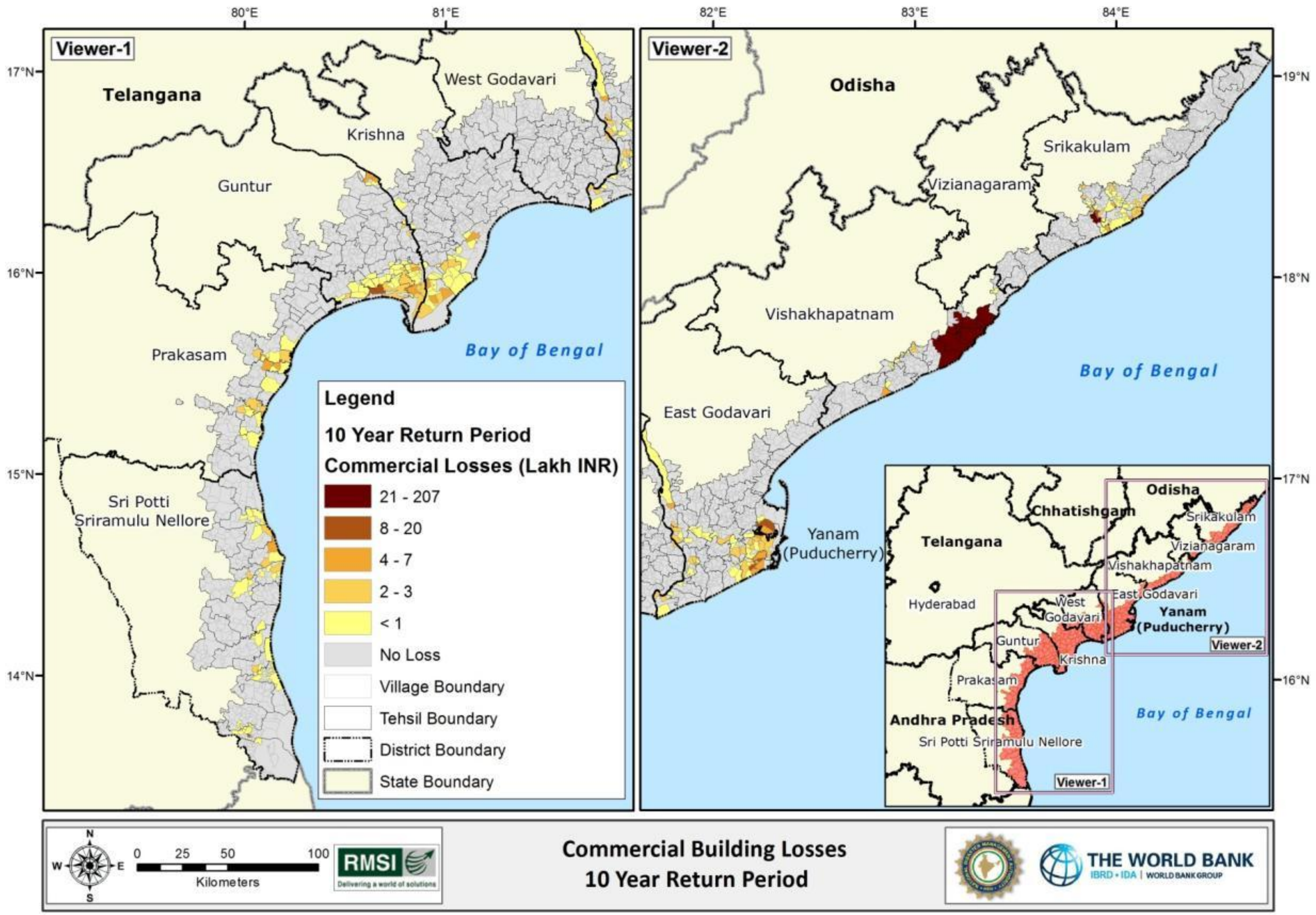

Figure 6-22: PML of commercial buildings due to cyclonic rainfall induced flood for a 10-year return period scenario, Andhra Pradesh

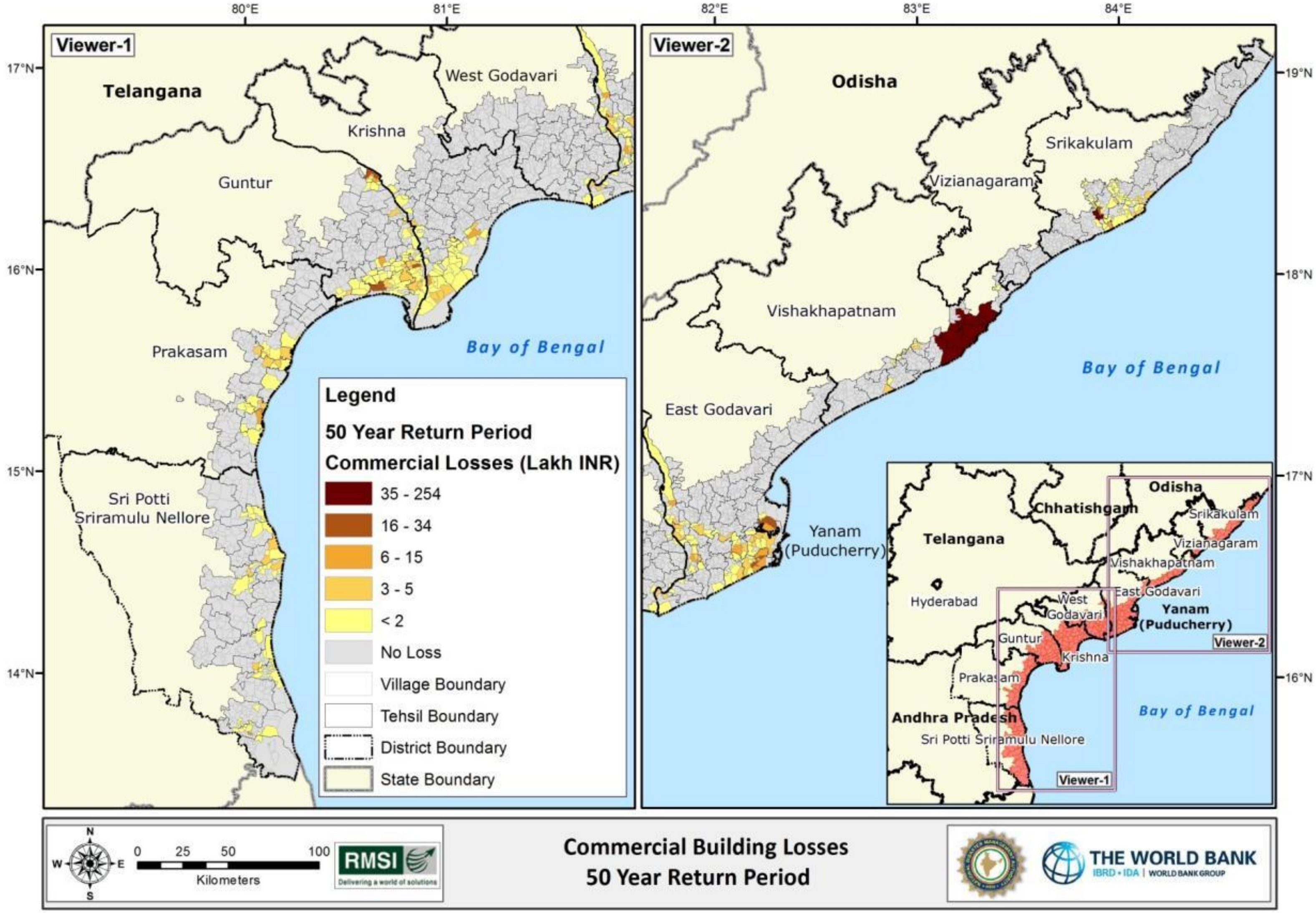

Figure 6-23: PML of commercial buildings due to cyclonic rainfall induced flood for a 50-year return period scenario, Andhra Pradesh

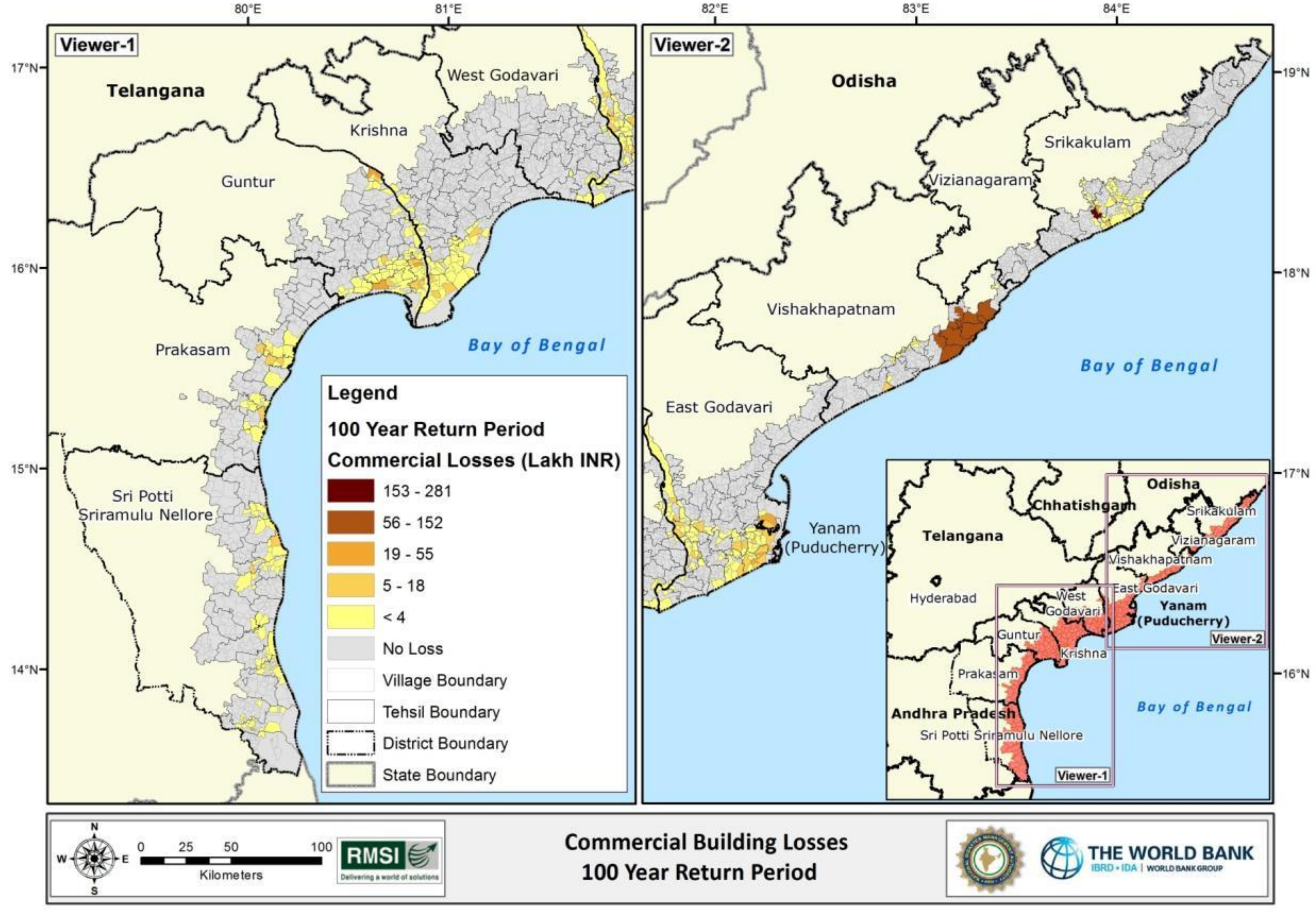

Figure 6-24: PML of commercial buildings (Andhra Pradesh) due to 100-Year Return Period Cyclone Induced Rainfall Flooding, Andhra Pradesh

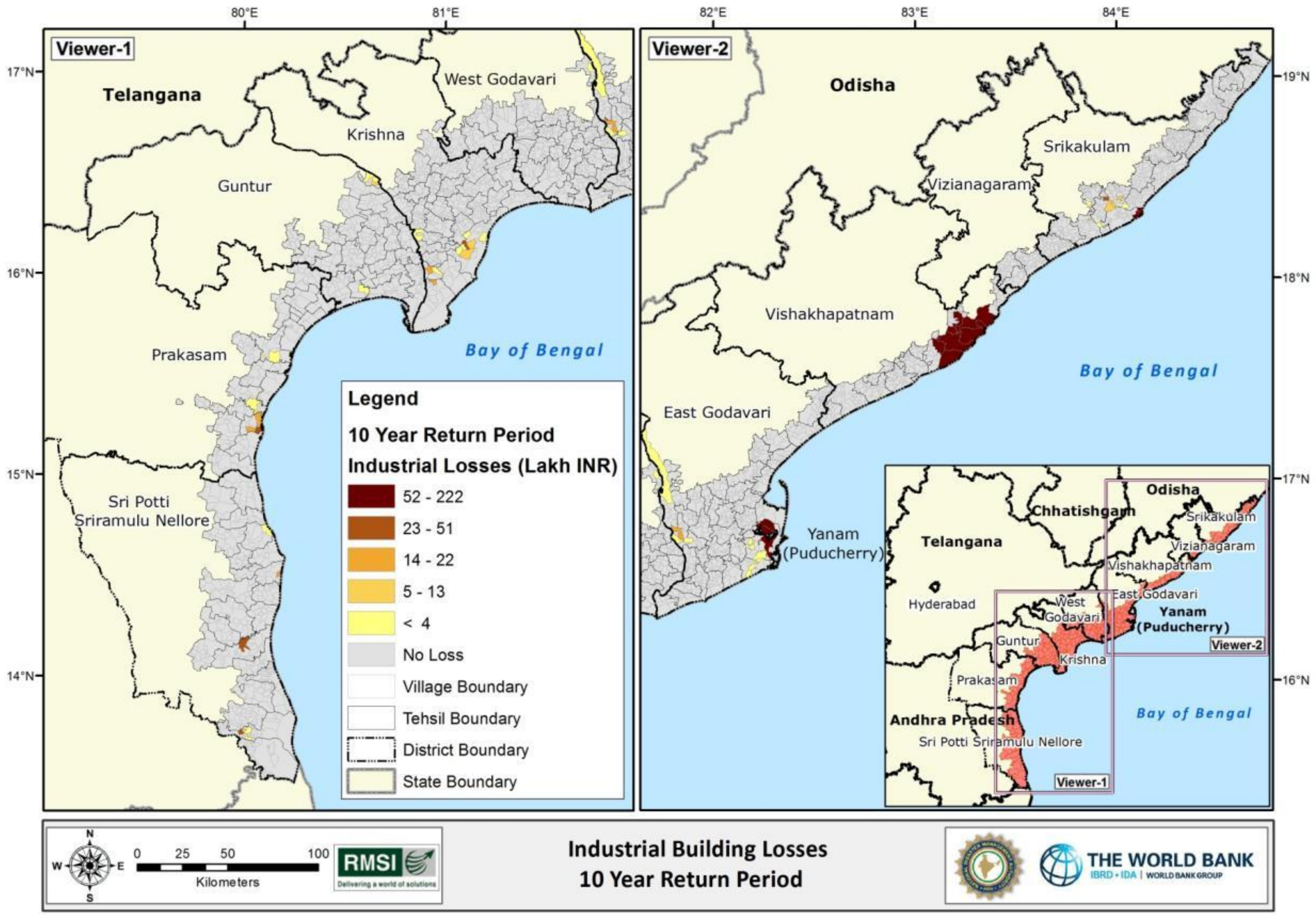

Figure 6-25: PML of industrial buildings due to cyclonic rainfall induced flood for a 10-year return period scenario, Andhra Pradesh

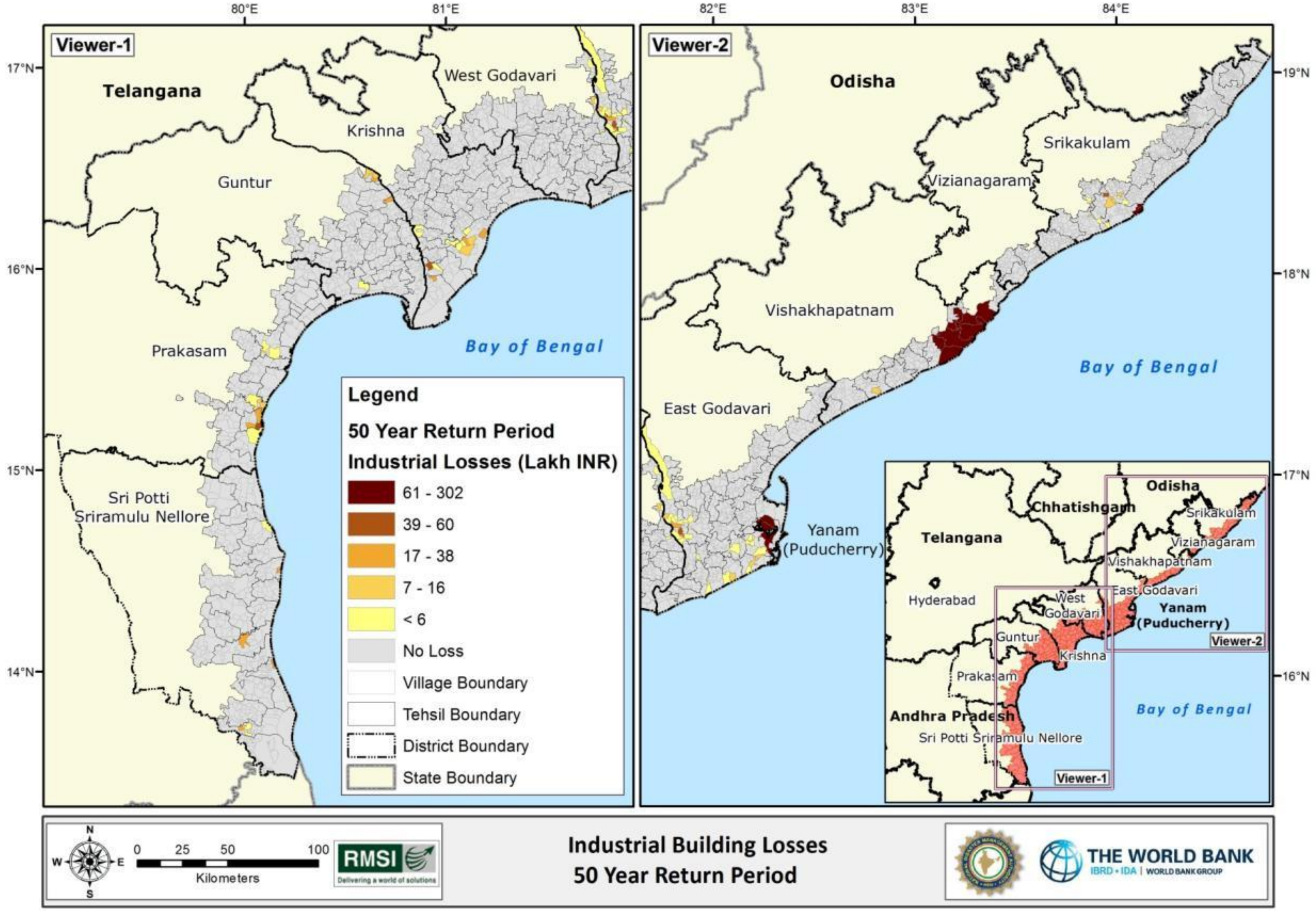

Figure 6-26: PML of industrial buildings due to cyclonic rainfall induced flood for a 50-year return period scenario, Andhra Pradesh

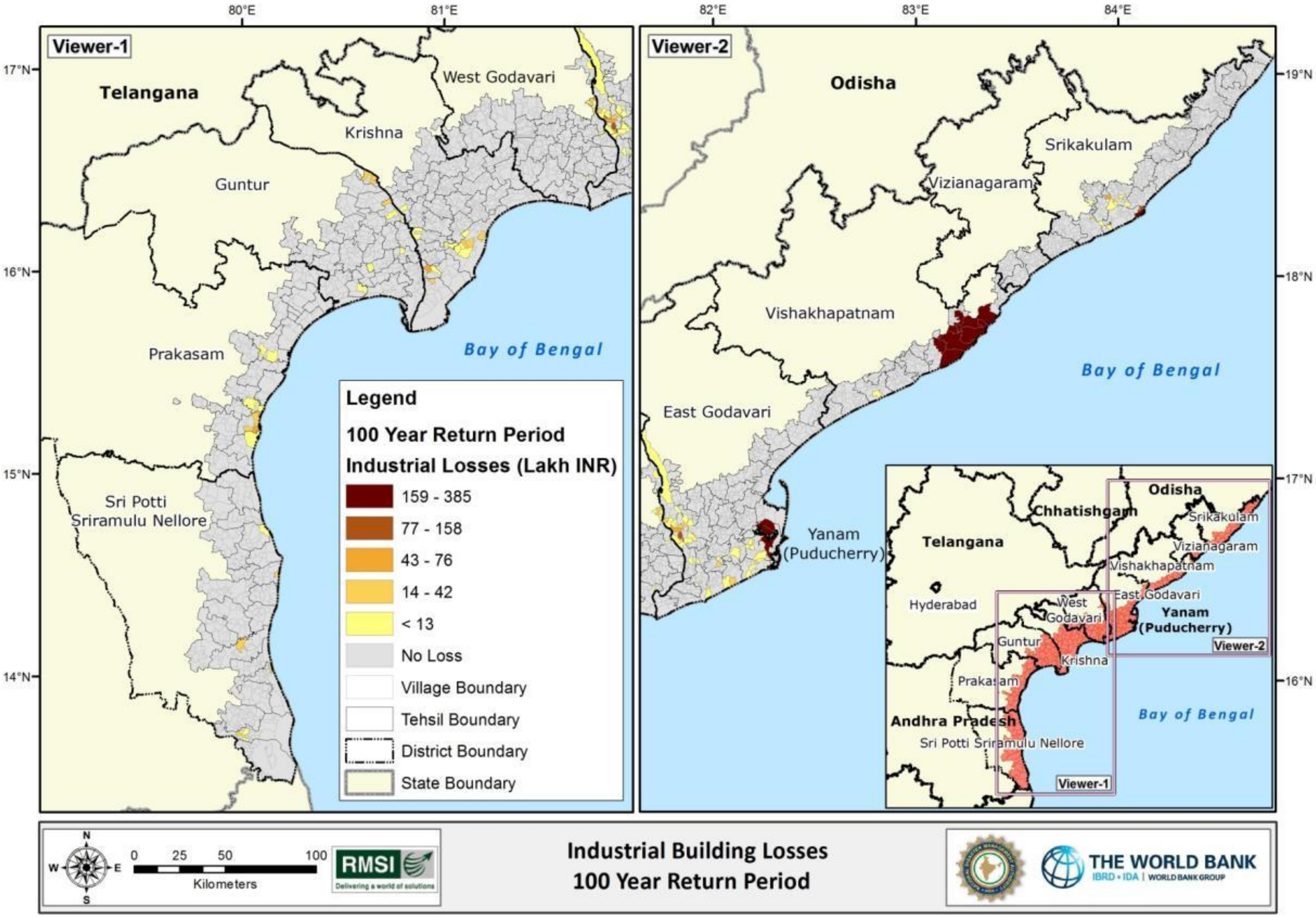

Figure 6-27: PML of industrial buildings due to cyclonic rainfall induced flood for a 100-year return period scenario, Andhra Pradesh

6.3.4 Composite Loss Maps for Andhra Pradesh

The composite loss maps for Andhra Pradesh have been prepared by aggregating the PML due to cyclonic wind, storm surge, and cyclonic rainfall induced flood for different return periods. The residential, commercial, and industrial building composite losses for 100-year return period scenario are given from Figure 6-28 to Figure 6-30. The residential composite loss maps depict that coastal areas of Sri Potti Sriramulu Nellore, Prakasam, East Godavari, and Vishakhapatnam districts are more likely to be affected as compared to other districts. The composite losses for commercial buildings in Vishakhapatnam and Srikakulam districts are more likely to be affected as compared to other districts, whereas the industrial composite losses are likely to be more in East Godavari, Sri Potti Sriramulu Nellore, and Vishakhapatnam districts.

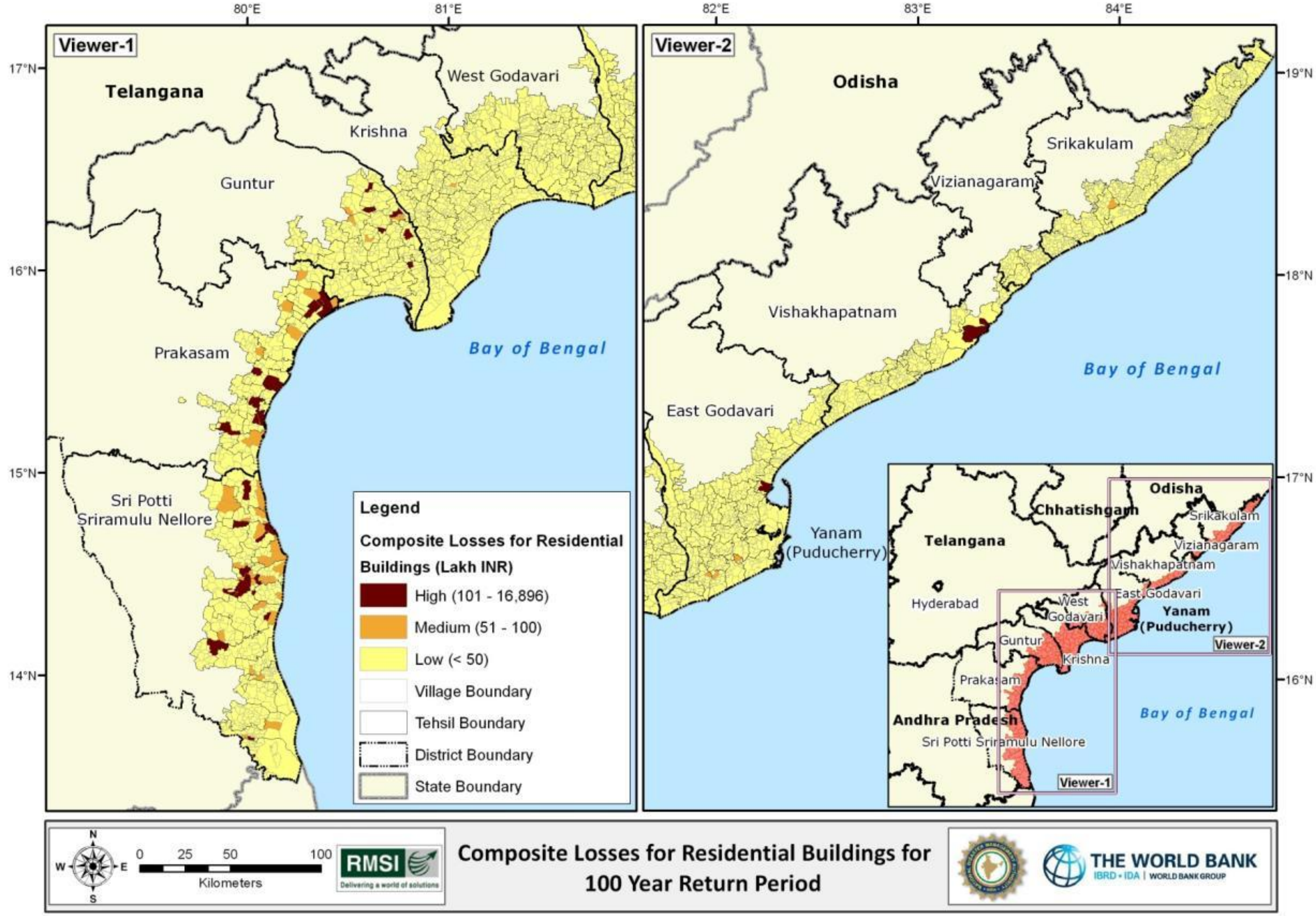

Figure 6-28: Composite losses for residential buildings for a 100-year return period scenario, Andhra Pradesh

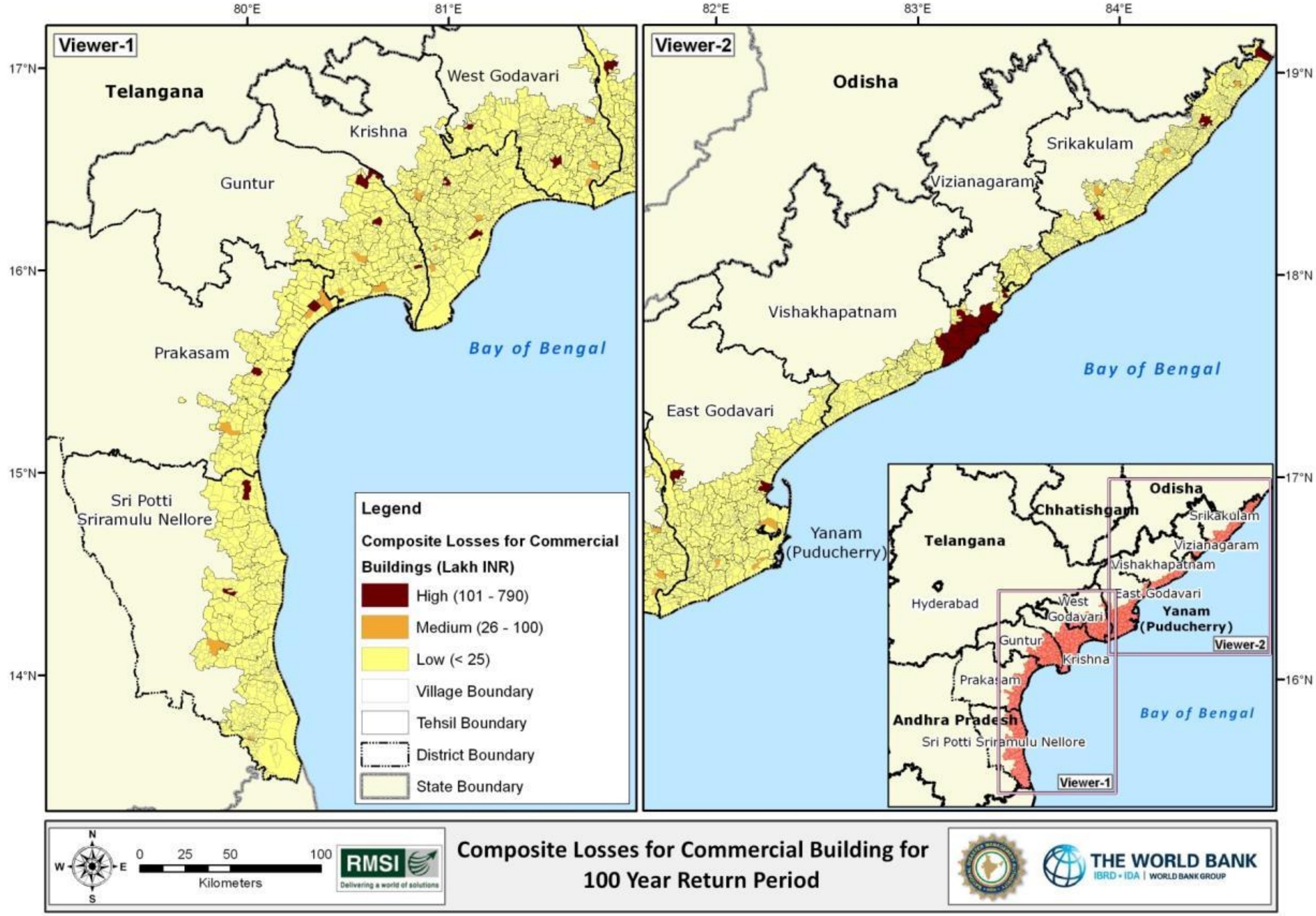

Figure 6-29: Composite losses for commercial buildings for a 100-year return period scenario, Andhra Pradesh

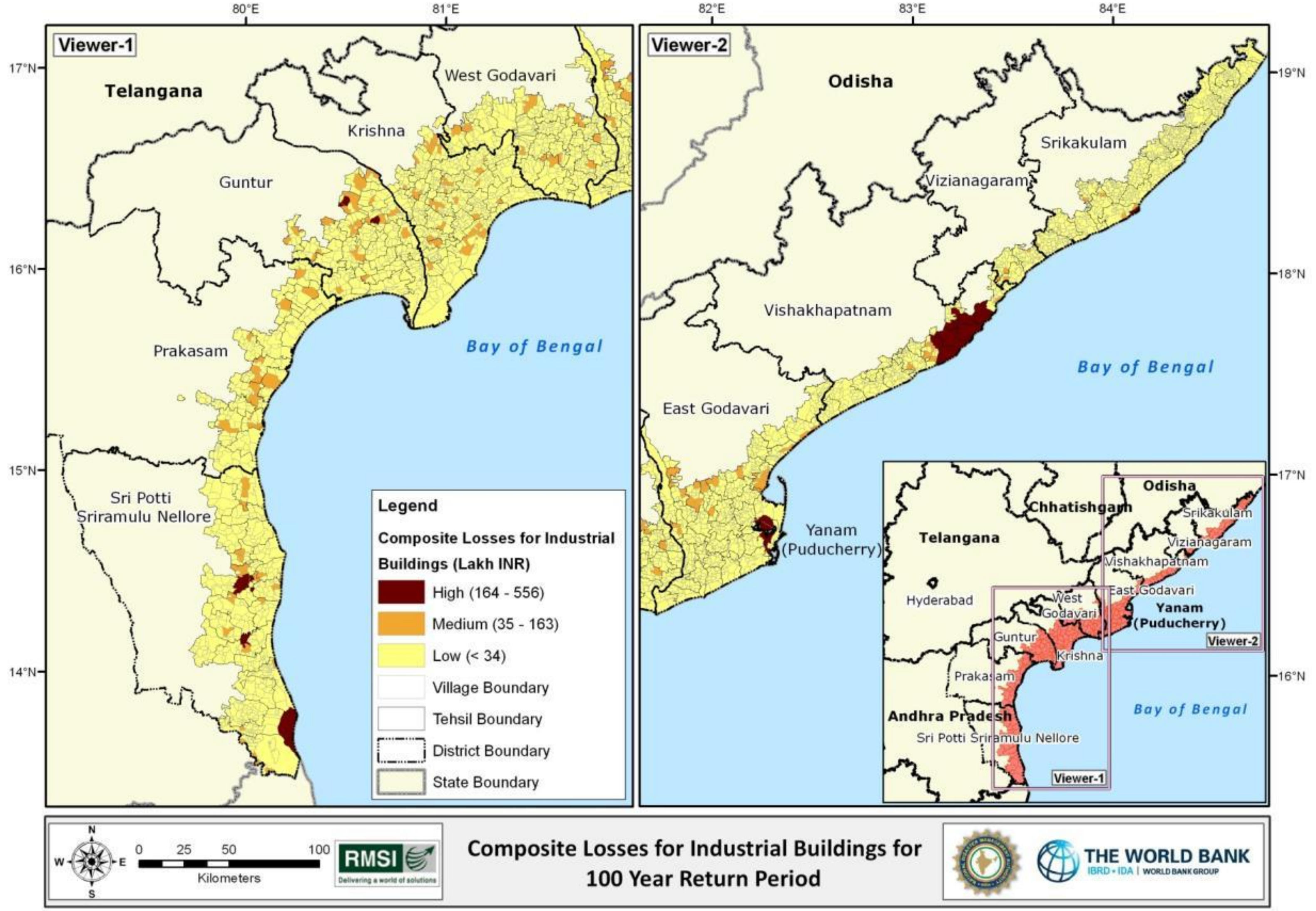

Figure 6-30: Composite losses for industrial buildings for a 100-year return period scenario, Andhra Pradesh

6.4 Loss Maps for Odisha

This section presents PML (Probable Maximum Loss) maps for residential, commercial, and industrial occupancy classes for key return period scenarios pertaining to the three hazards considered, namely cyclonic wind, storm surge, and cyclone induced rainfall flood. As stated above, it may be noted that the PML for 2 and 5-year return periods for all three hazards are insignificant when compared to PML for higher return periods.

The residential, commercial, and industrial building losses for various probabilistic scenarios (10, 50, and 100 year return periods) for Odisha are given from Figure 6-49 to Figure 6-57. The coastal areas of Baleshwar, Bhadrak, Kendrapara, Jajpur and Jagatsinghpur districts are likely to be affected more for Residential, Commercial and Industrial building exposure. The losses in Kendrapara, Bhadrak and Jajpur are mainly driven by cyclone induced rainfall flood hazard as these areas are severely affected due to flooding whereas the losses in Puri and Jagatsinghpur are mainly driven by their higher exposure.

6.4.1 PML MAPS FOR CYCLONIC WIND

The residential, commercial, and industrial building losses for various probabilistic scenarios (10, 50, and 100 year return periods) for Odisha are given from Figure 6-31 to Figure 6-39. The coastal areas of Baleshwar, Ganjam, Kendrapara, Jagatsinghpur, Puri, and Cuttack districts are likely to be affected more for Residential, Commercial and Industrial building exposure. The losses in Jagatsinghpur, Kendrapara, and Ganjam are mainly driven by cyclonic wind hazard as these areas are severely affected due to strong winds whereas the losses in Puri and Jagatsinghpur are mainly driven by their higher exposure.

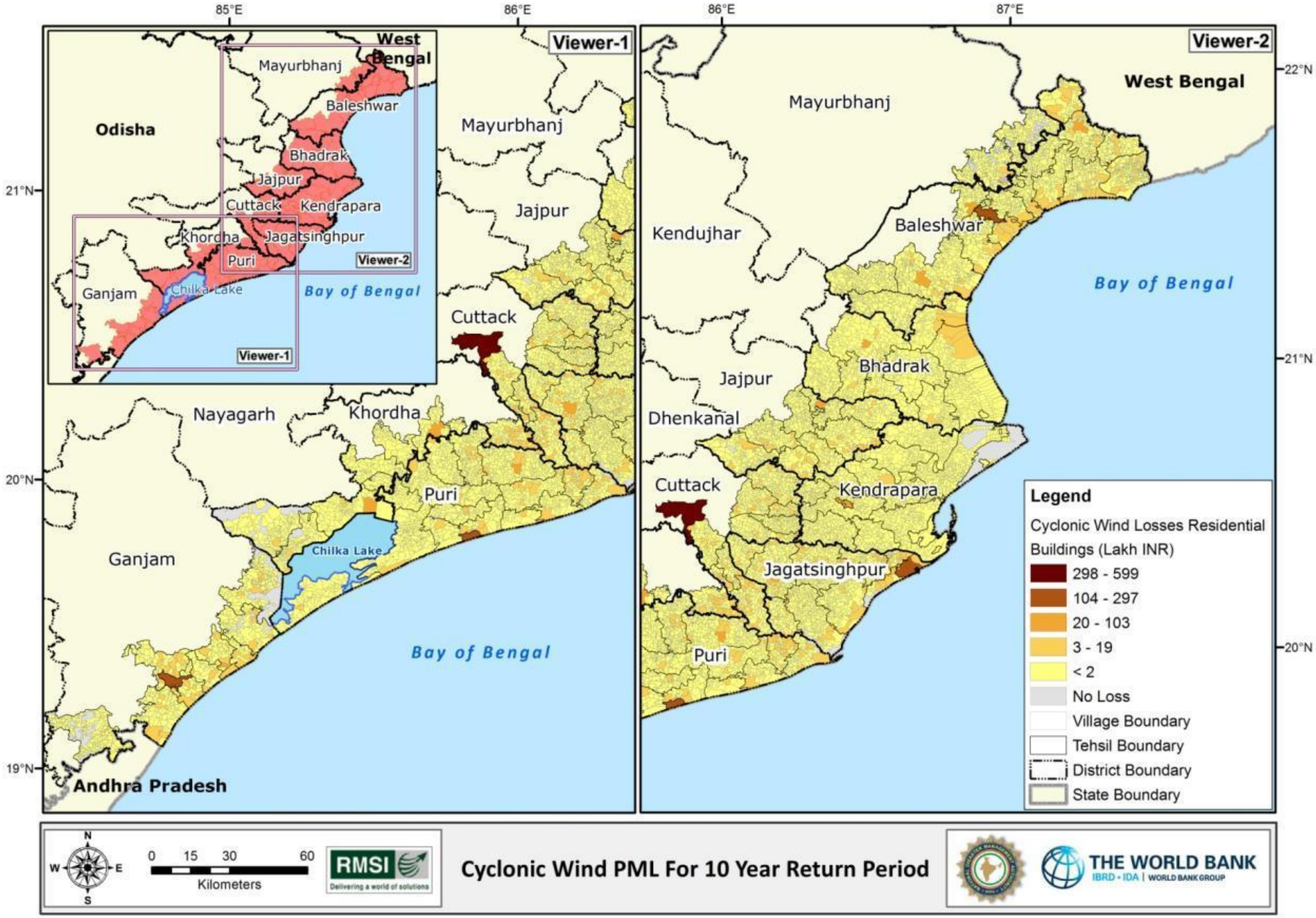

Figure 6-31: PML of residential buildings due to cyclonic wind for a 10-year return period scenario, Odisha

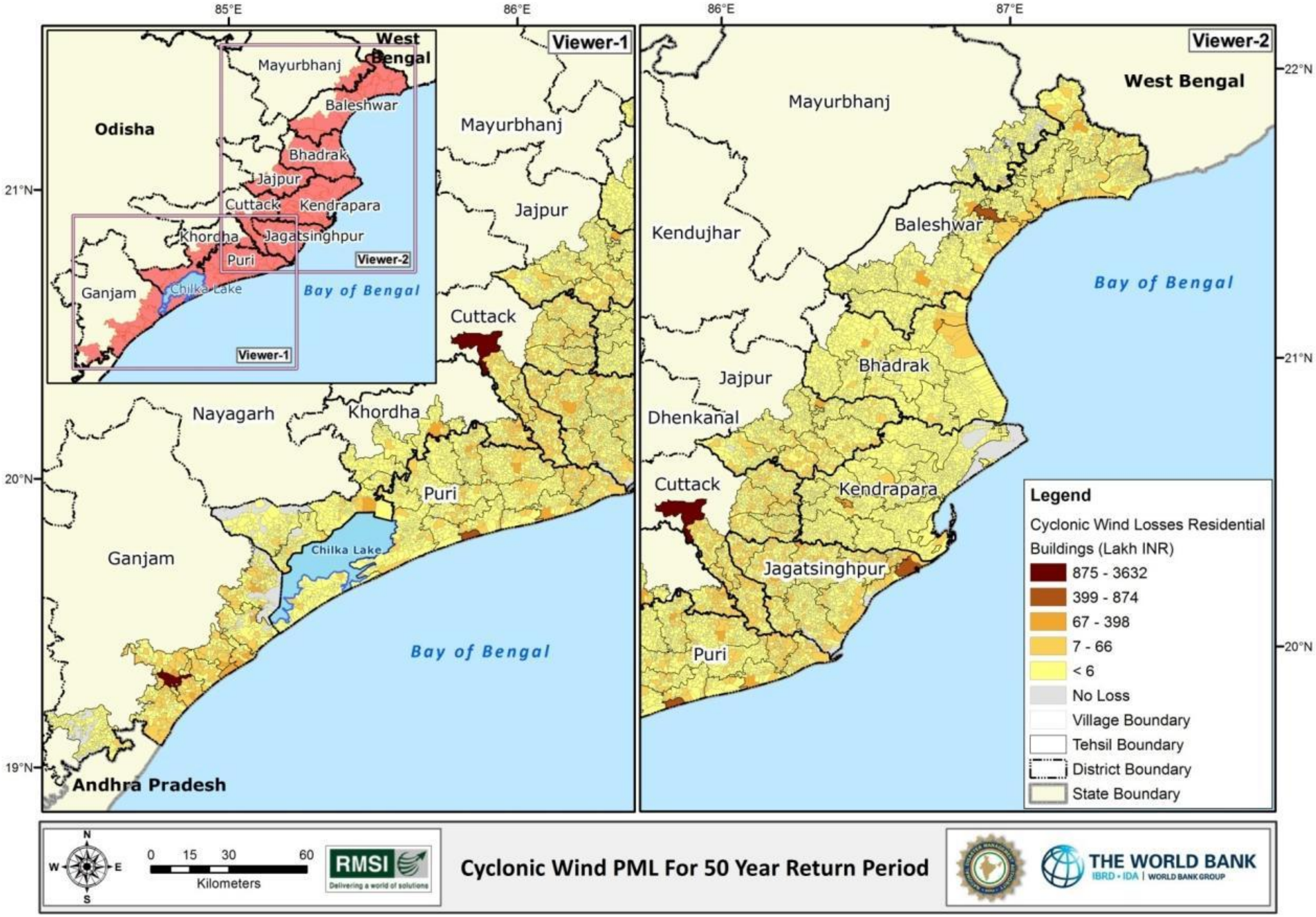

Figure 6-32: PML of residential buildings due to cyclonic wind for a 50-year return period scenario, Odisha

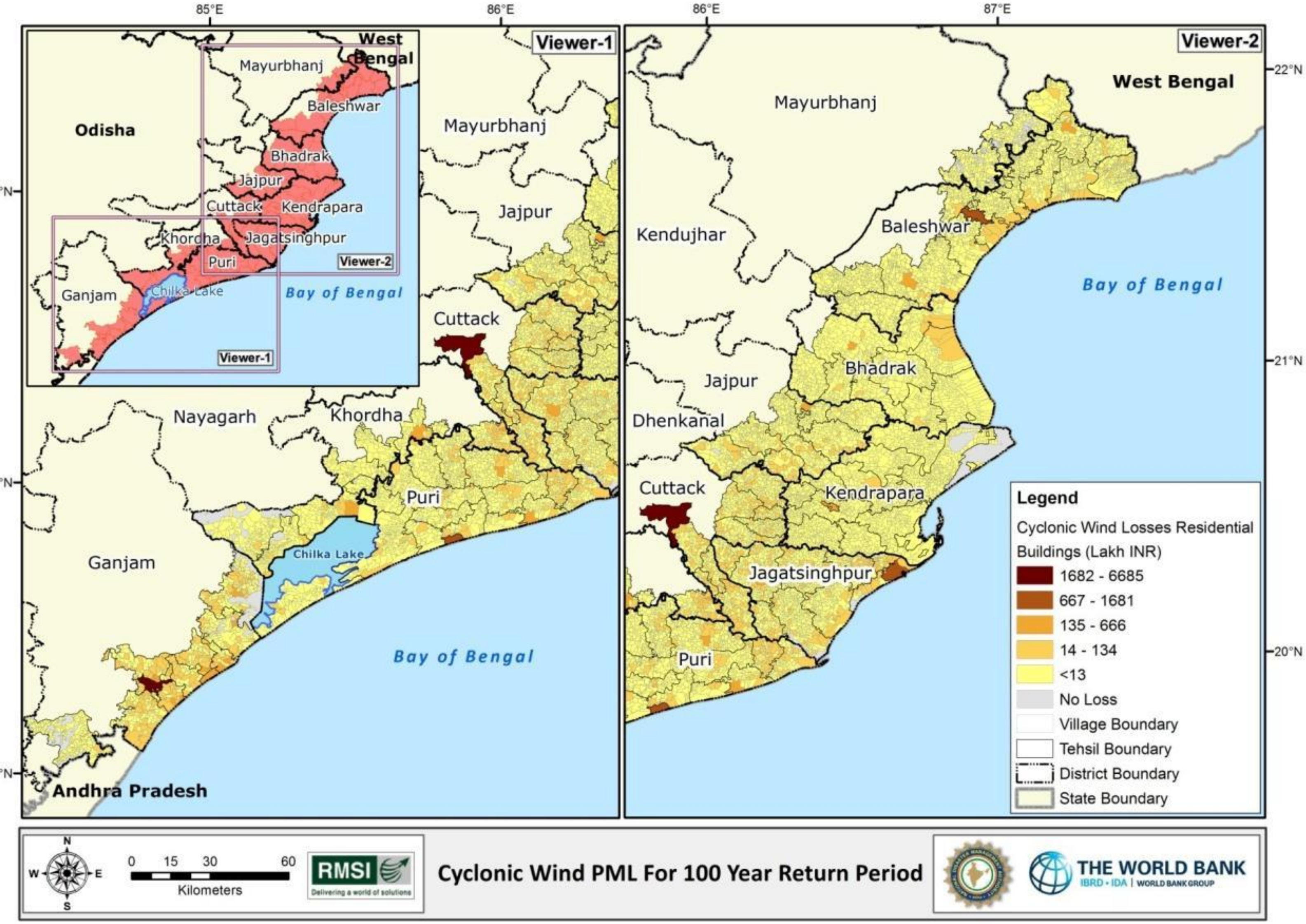

Figure 6-33: PML of residential buildings due to cyclonic wind for a 100-year return period scenario, Odisha

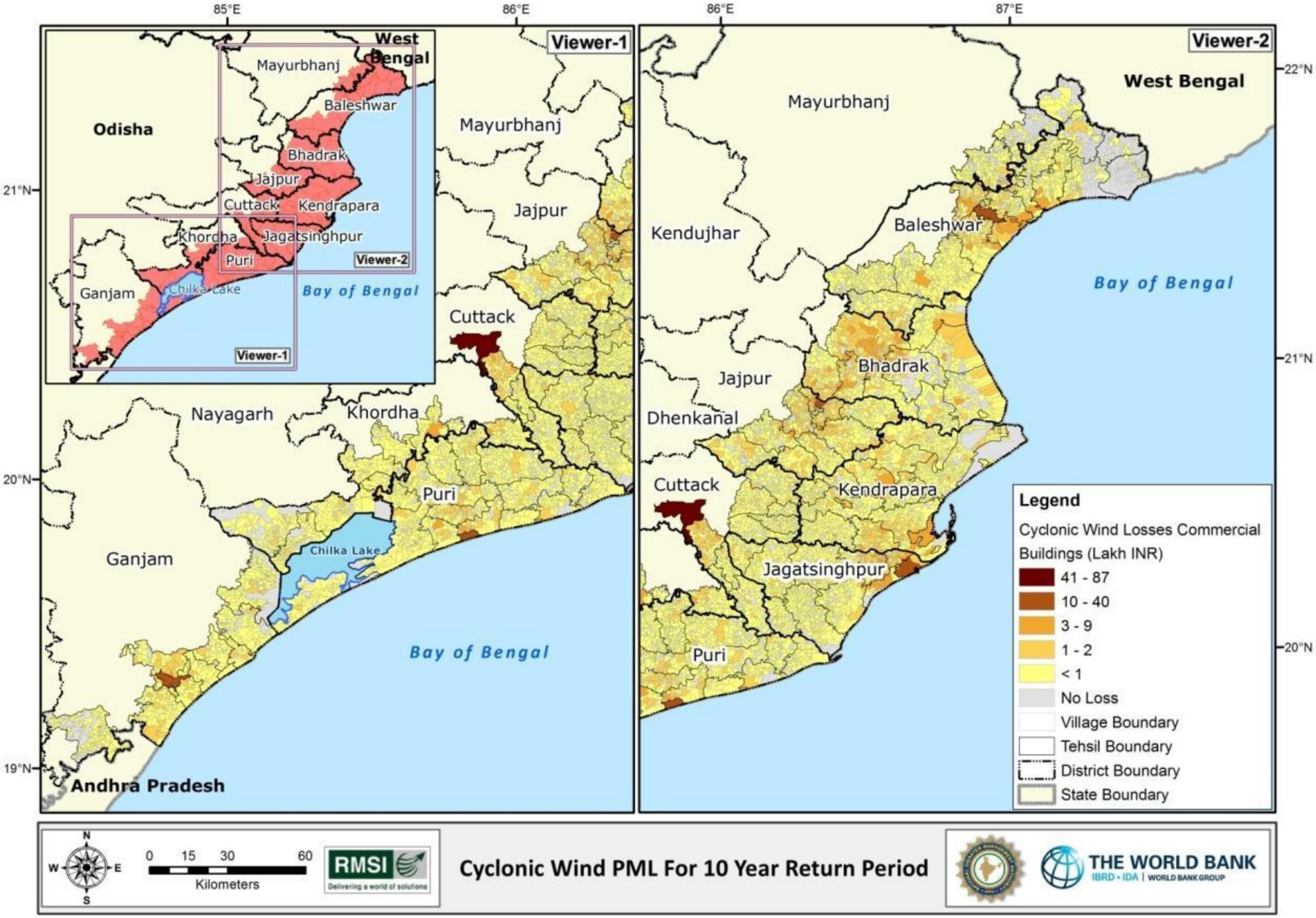

Figure 6-34: PML of commercial buildings due to cyclonic wind for a 10-year return period scenario, Odisha

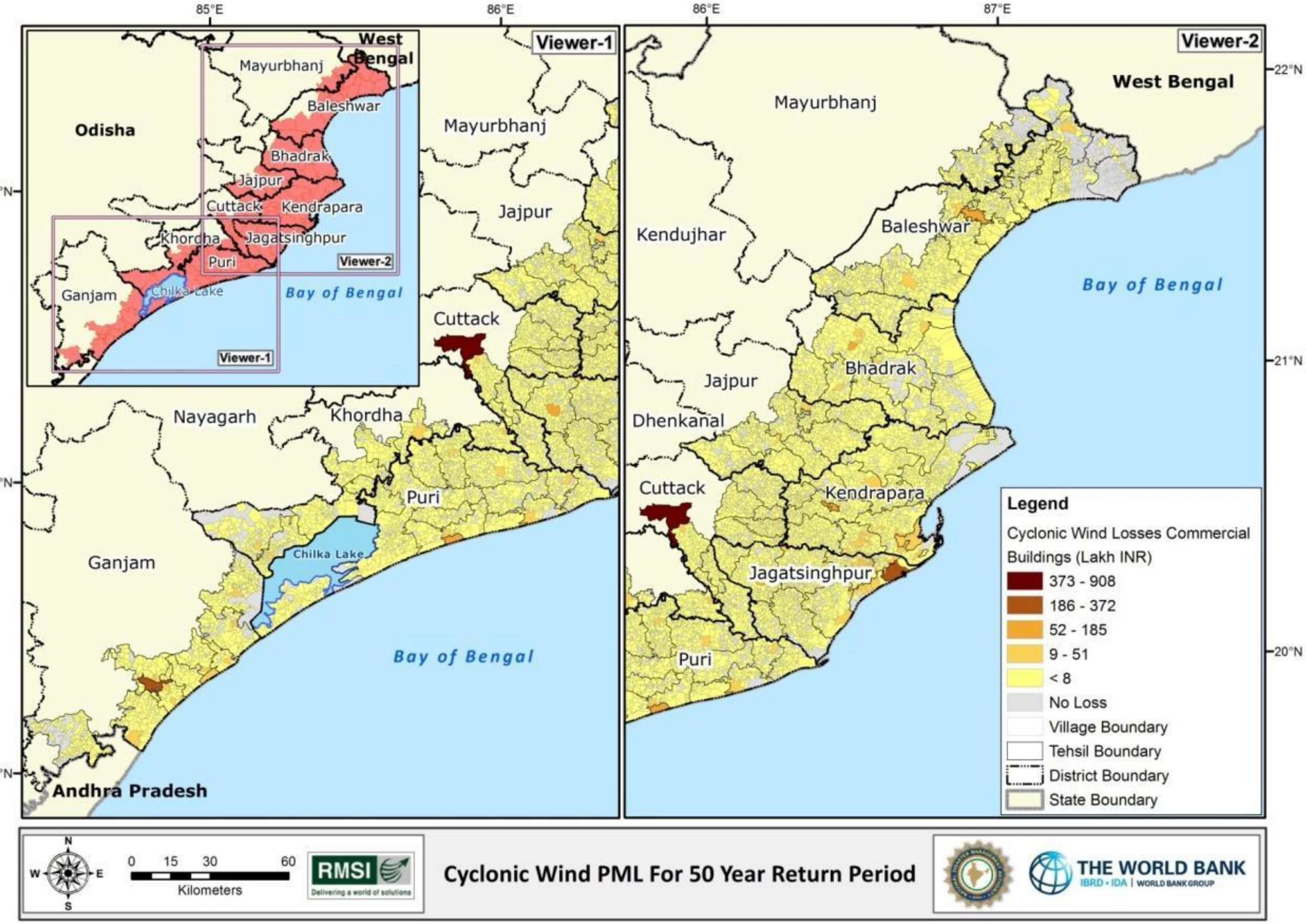

Figure 6-35: PML of commercial buildings due to cyclonic wind for a 50-year return period scenario, Odisha

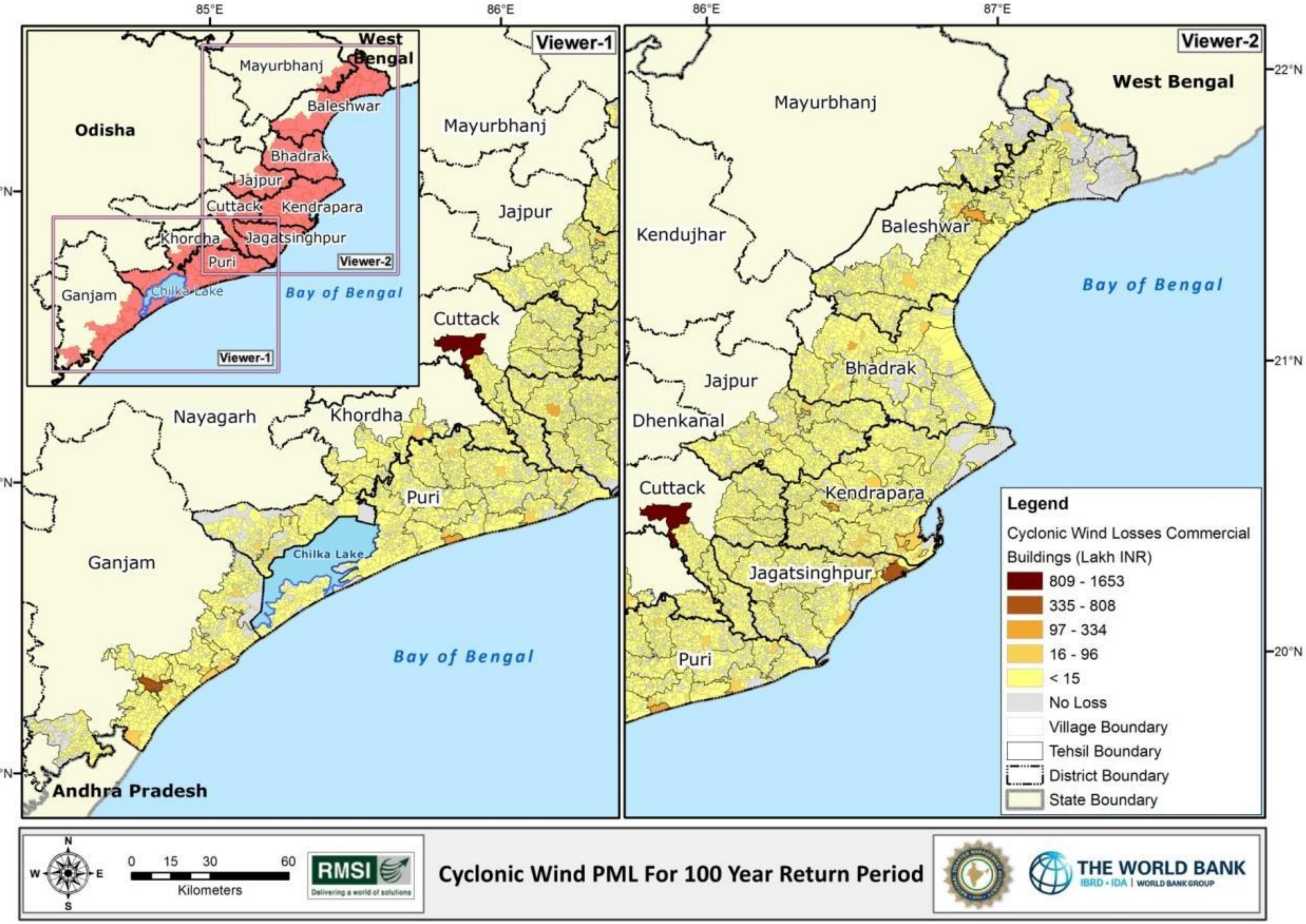

Figure 6-36: PML of commercial buildings due to cyclonic wind for a 100-year return period scenario, Odisha

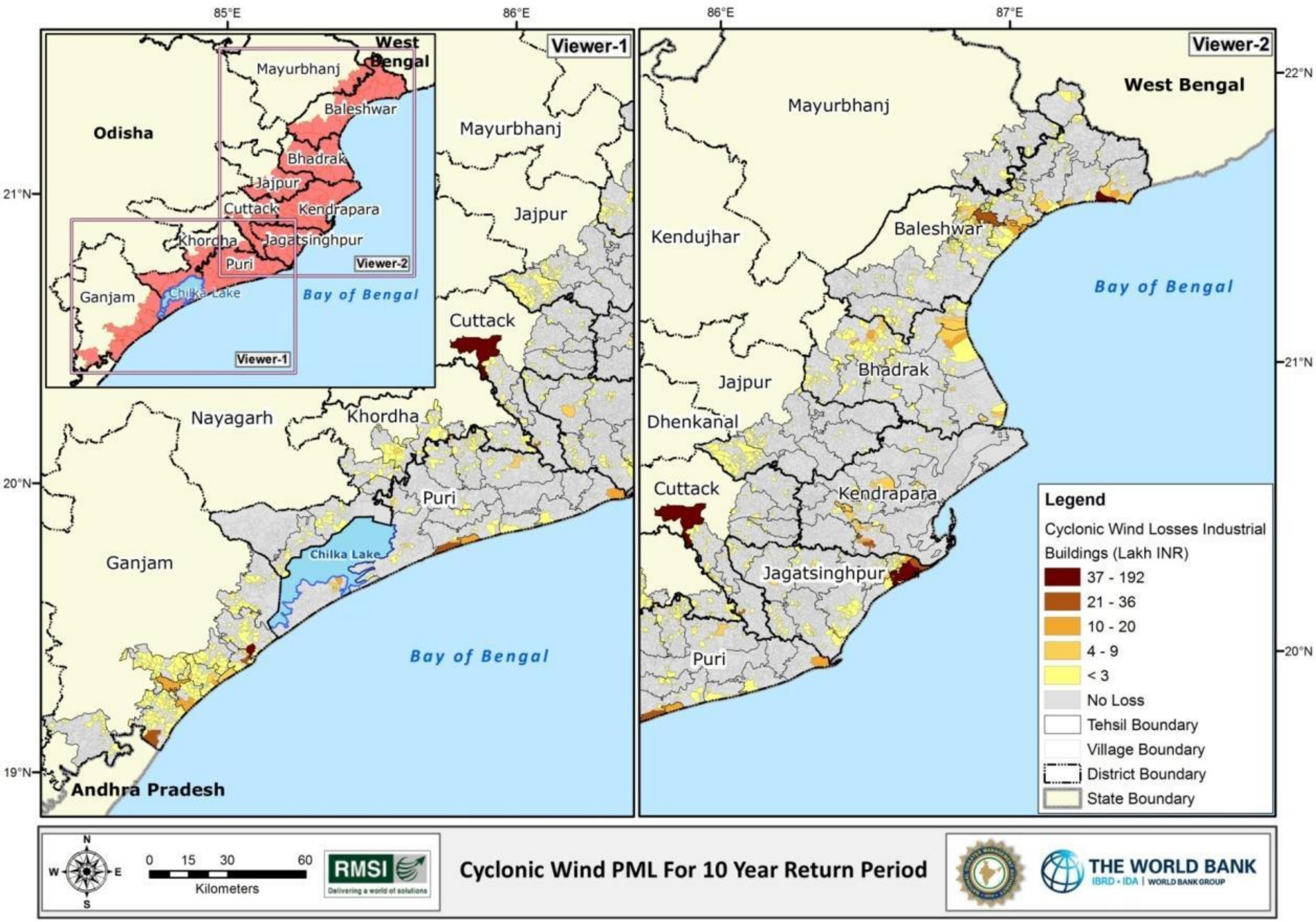

Figure 6-37: PML of industrial buildings due to cyclonic wind for a 10-year return period scenario, Odisha

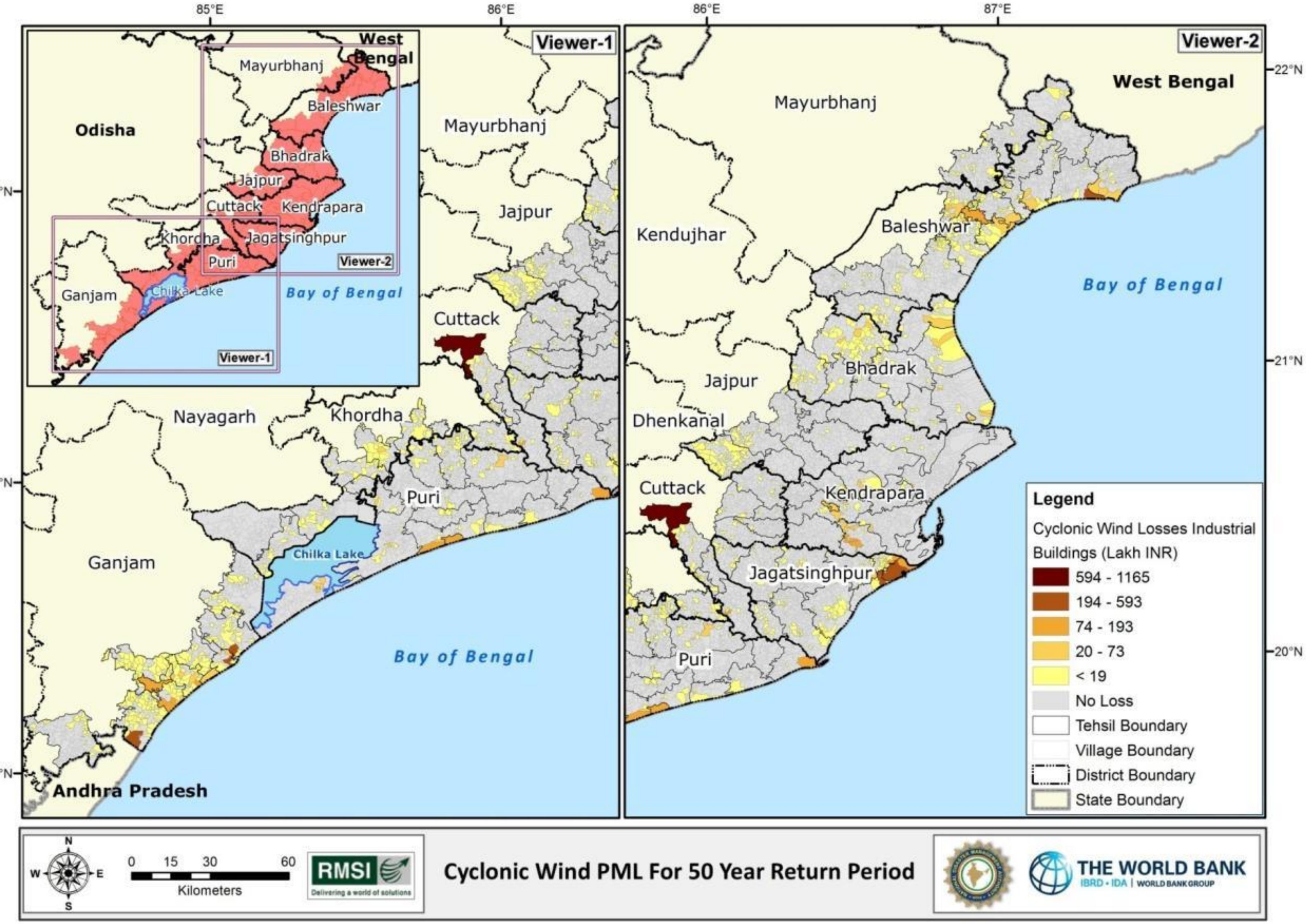

Figure 6-38: PML of industrial buildings due to cyclonic wind for a 50-year return period scenario, Odisha

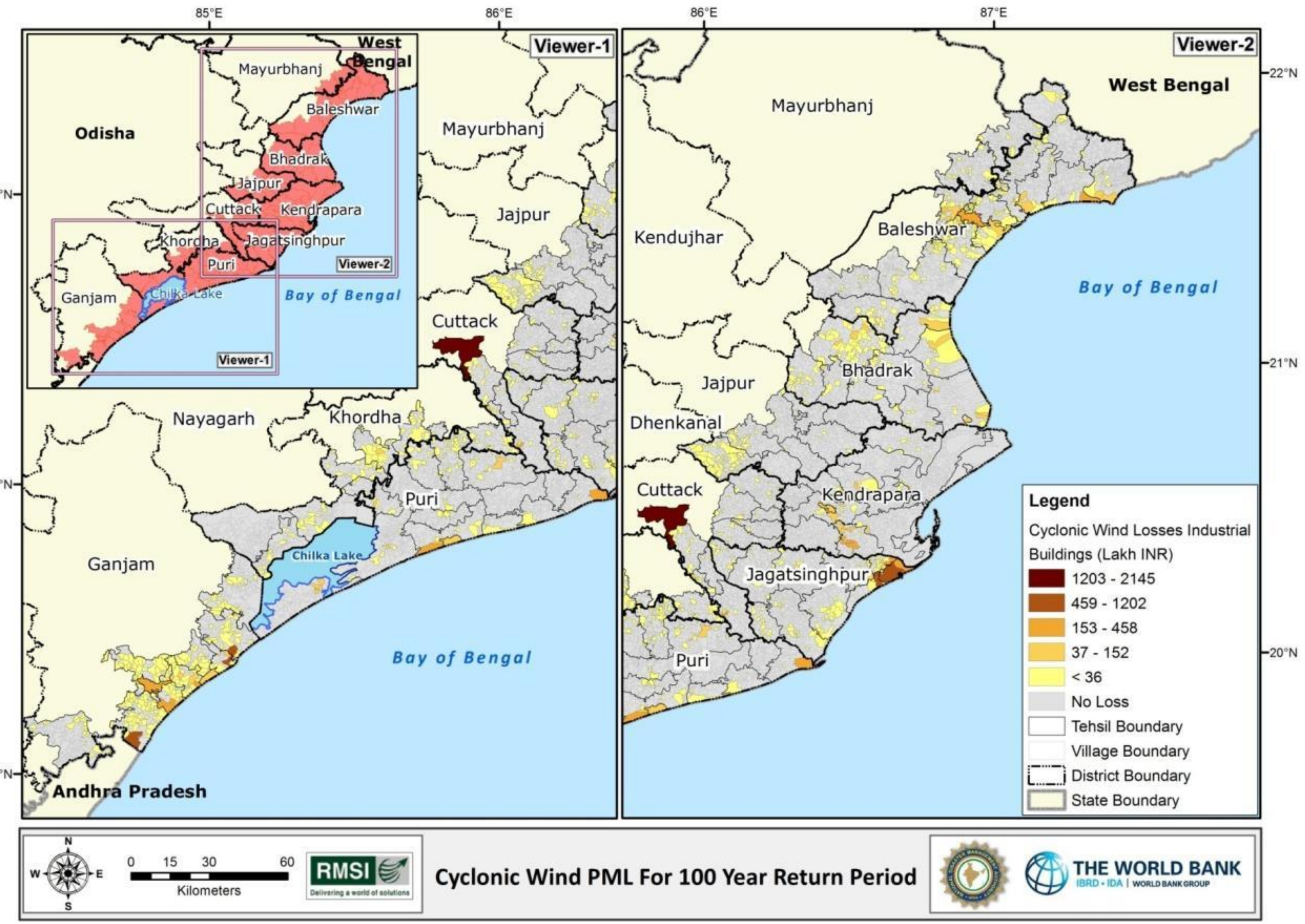

Figure 6-39: PML of industrial buildings due to cyclonic wind for a 100-year return period scenario, Odisha

6.4.2 PML MAPS FOR STORM SURGE

The residential, commercial, and industrial building losses for various probabilistic scenarios (10, 50, and 100 year return periods) for Odisha are given from Figure 6-40 to Figure 6-48. The coastal areas of Baleshwar, Bhadrak, Kendrapara, and Jagatsinghpur districts are likely to be affected more for Residential, Commercial and Industrial building exposure. The losses in Jagatsinghpur, Kendrapara, and Bhadrak are mainly driven by storm surge hazard as these areas are severely affected due to flooding whereas the losses in Jagatsinghpur and Kendrapara are mainly driven by their higher exposure.

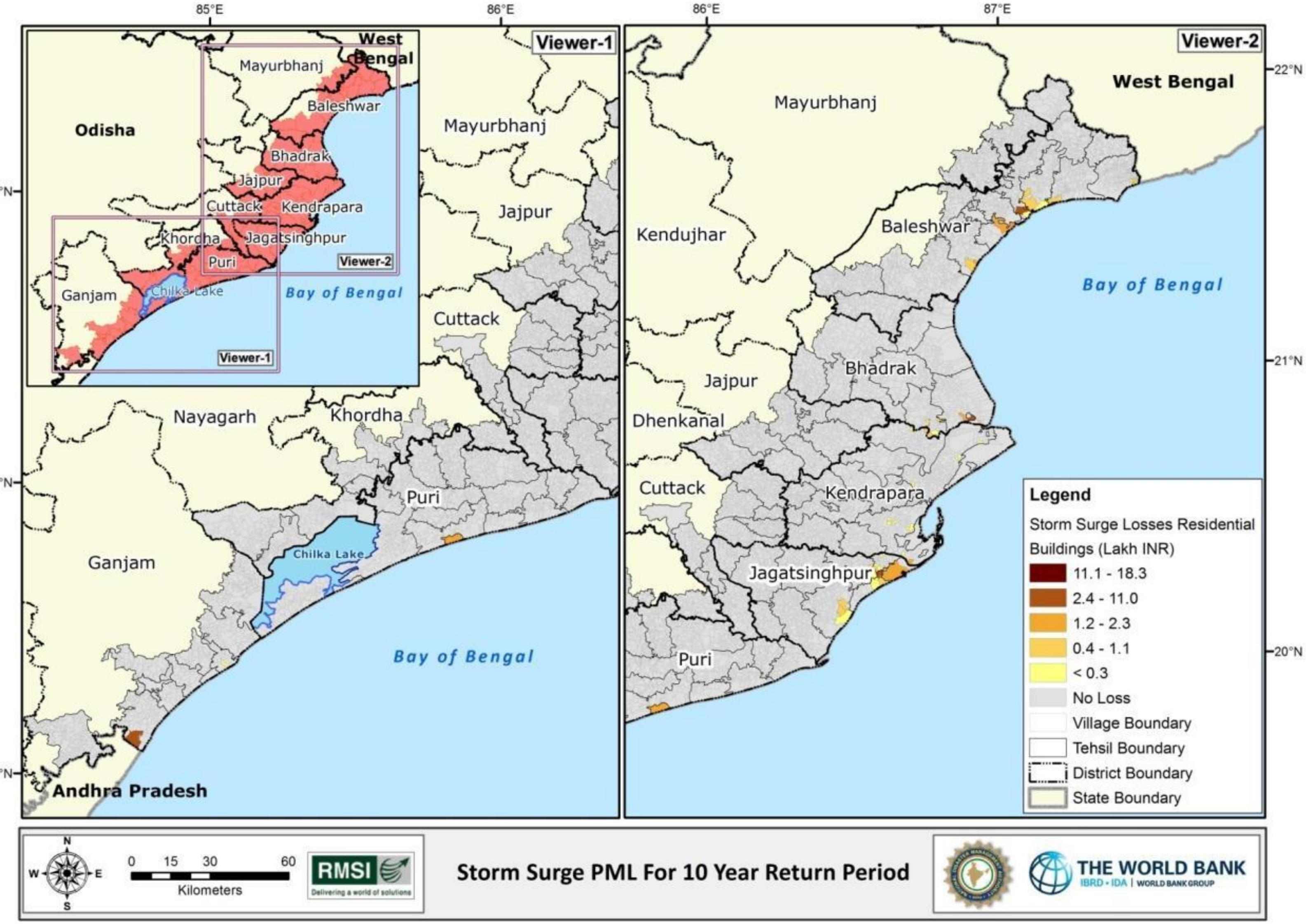

Figure 6-40: PML of residential buildings due to storm surge for a 10-year return period scenario, Odisha

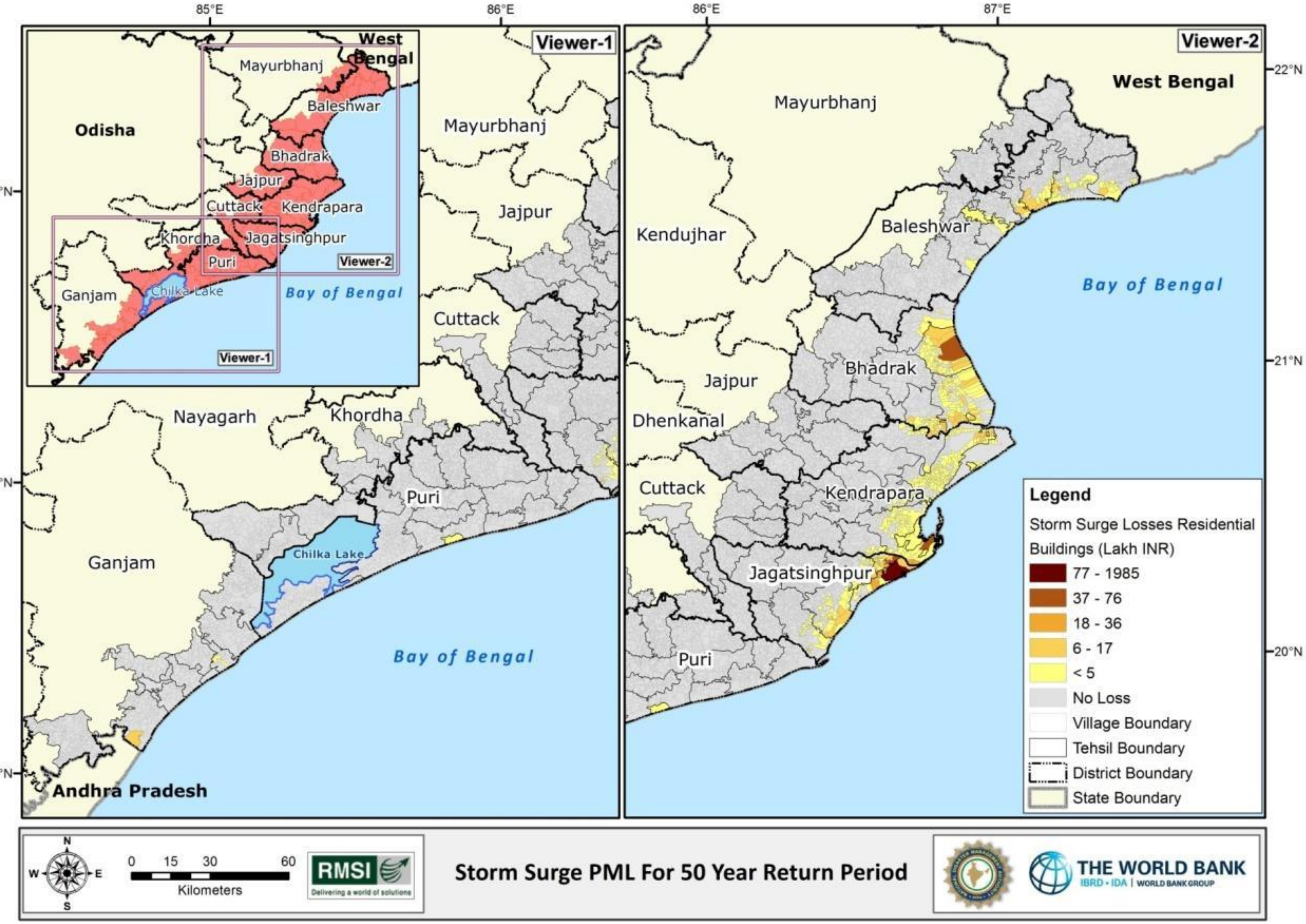

Figure 6-41: PML of residential buildings due to storm surge for a 50-year return period scenario, Odisha

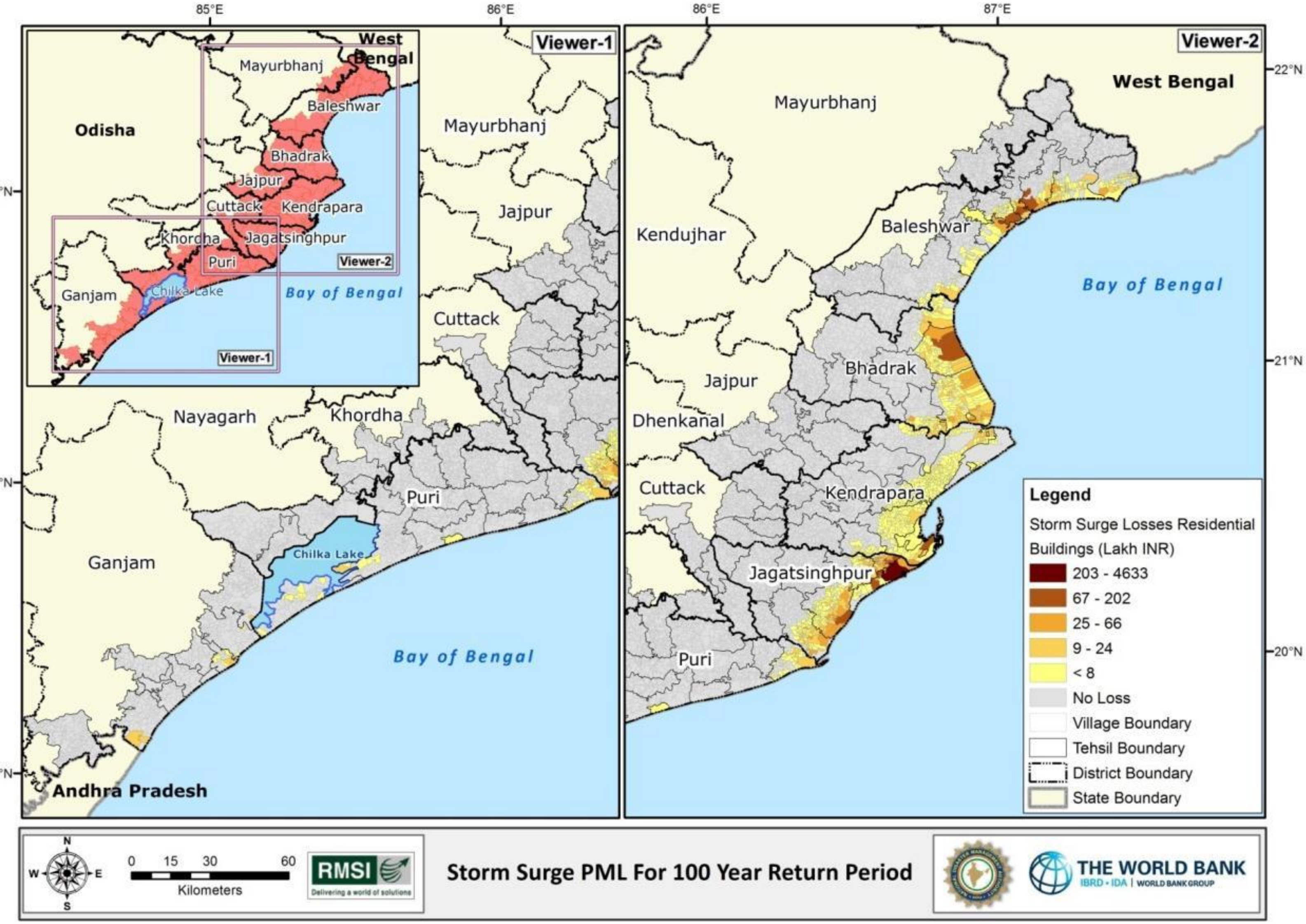

Figure 6-42: PML of to residential buildings due to storm surge for a 100-year return period scenario, Odisha

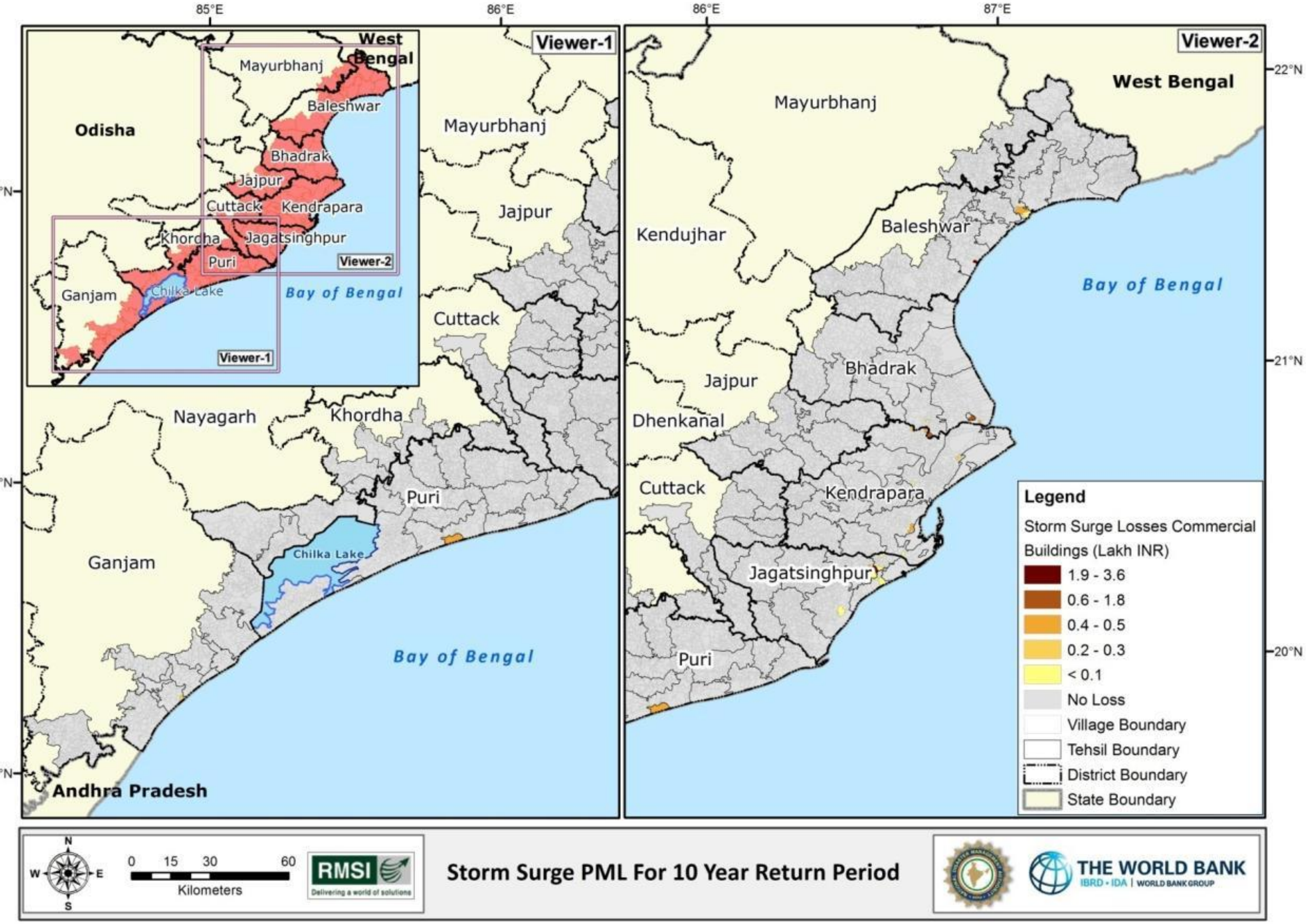

Figure 6-43: PML of commercial buildings due to storm surge for a 10-year return period scenario, Odisha

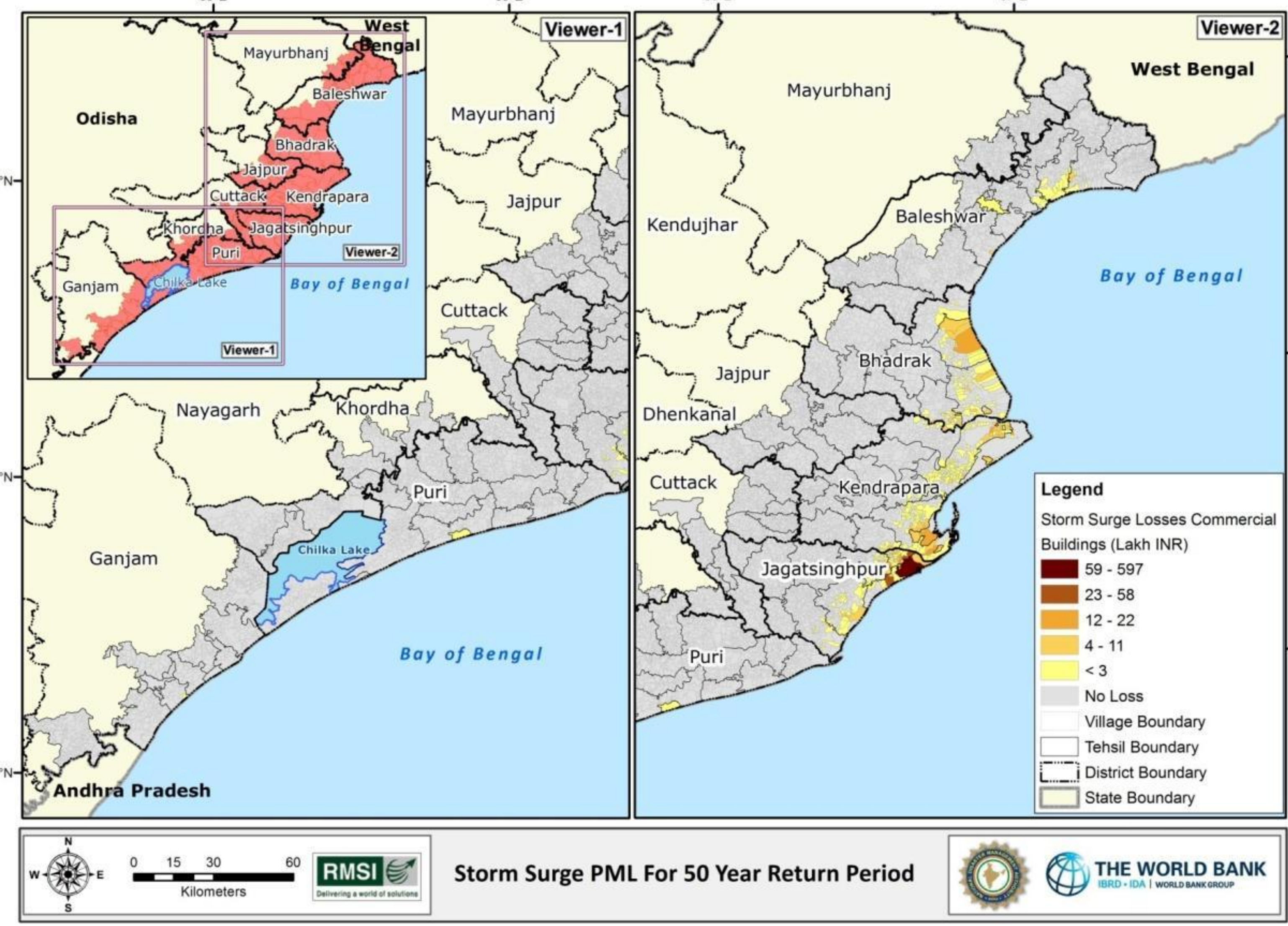

Figure 6-44: PML of commercial buildings due to storm surge for a 50-year return period scenario, Odisha

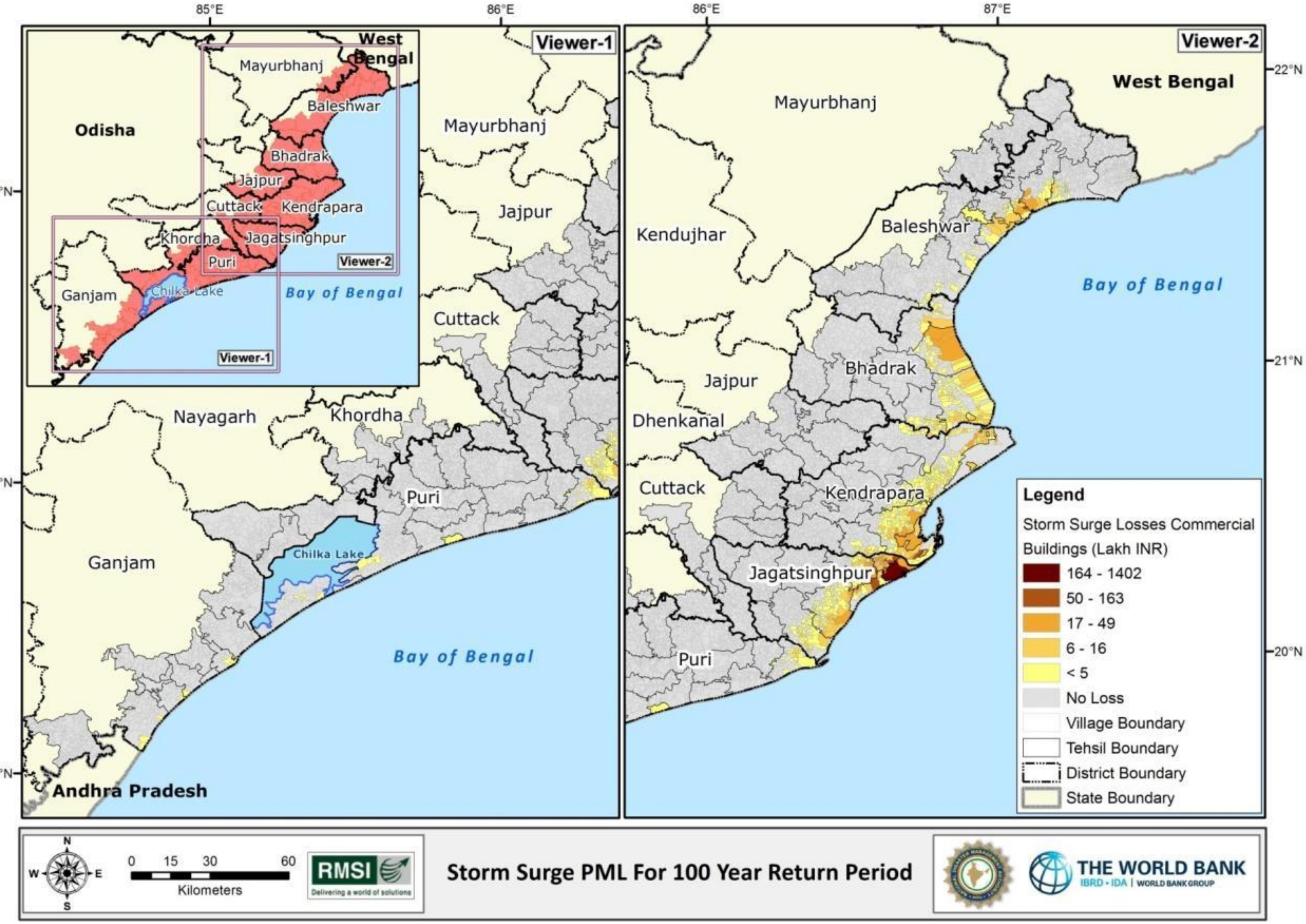

Figure 6-45: PML of commercial buildings due to storm surge for a 100-year return period scenario, Odisha

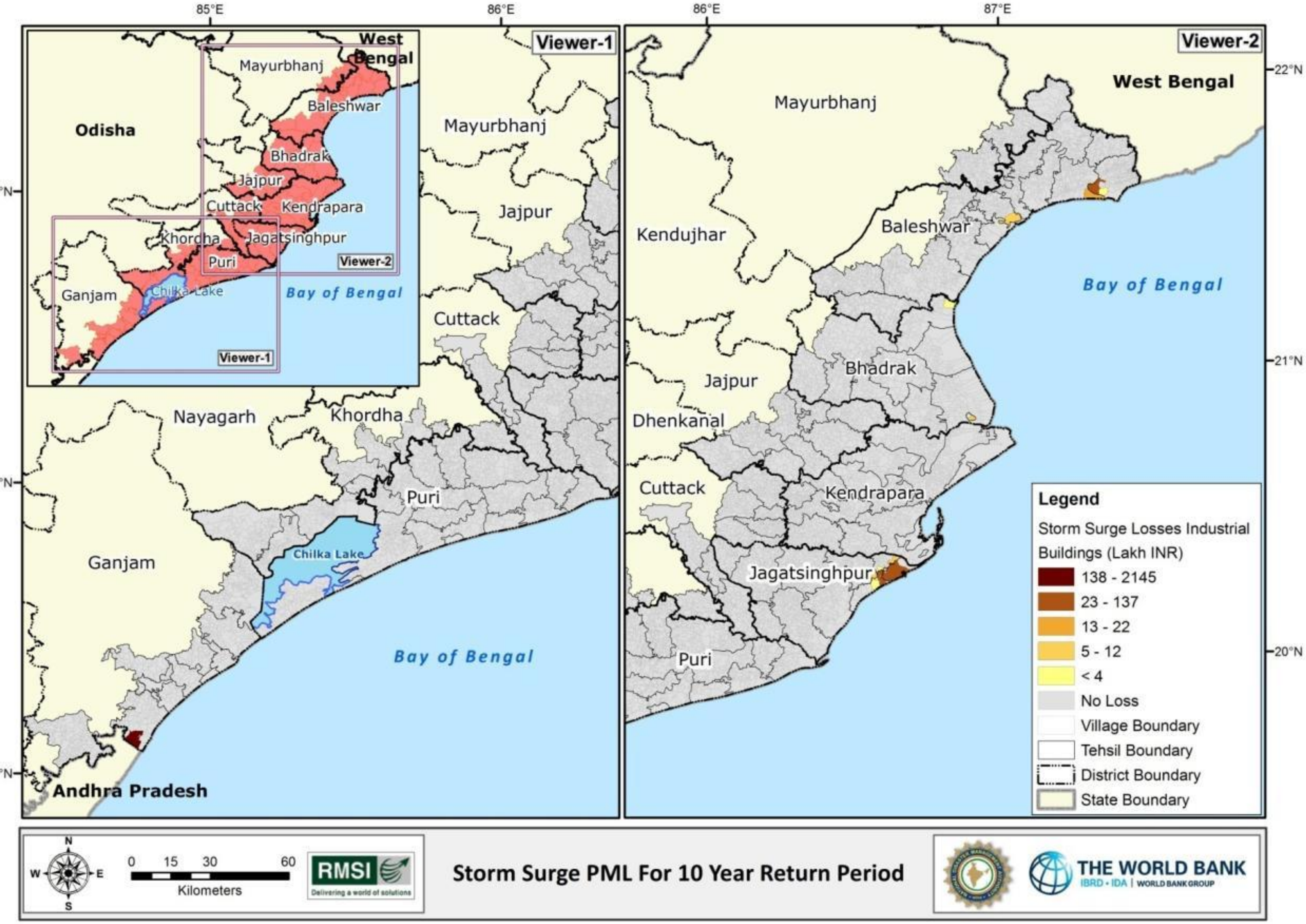

Figure 6-46: PML of industrial buildings due to storm surge for a 10-year return period scenario, Odisha

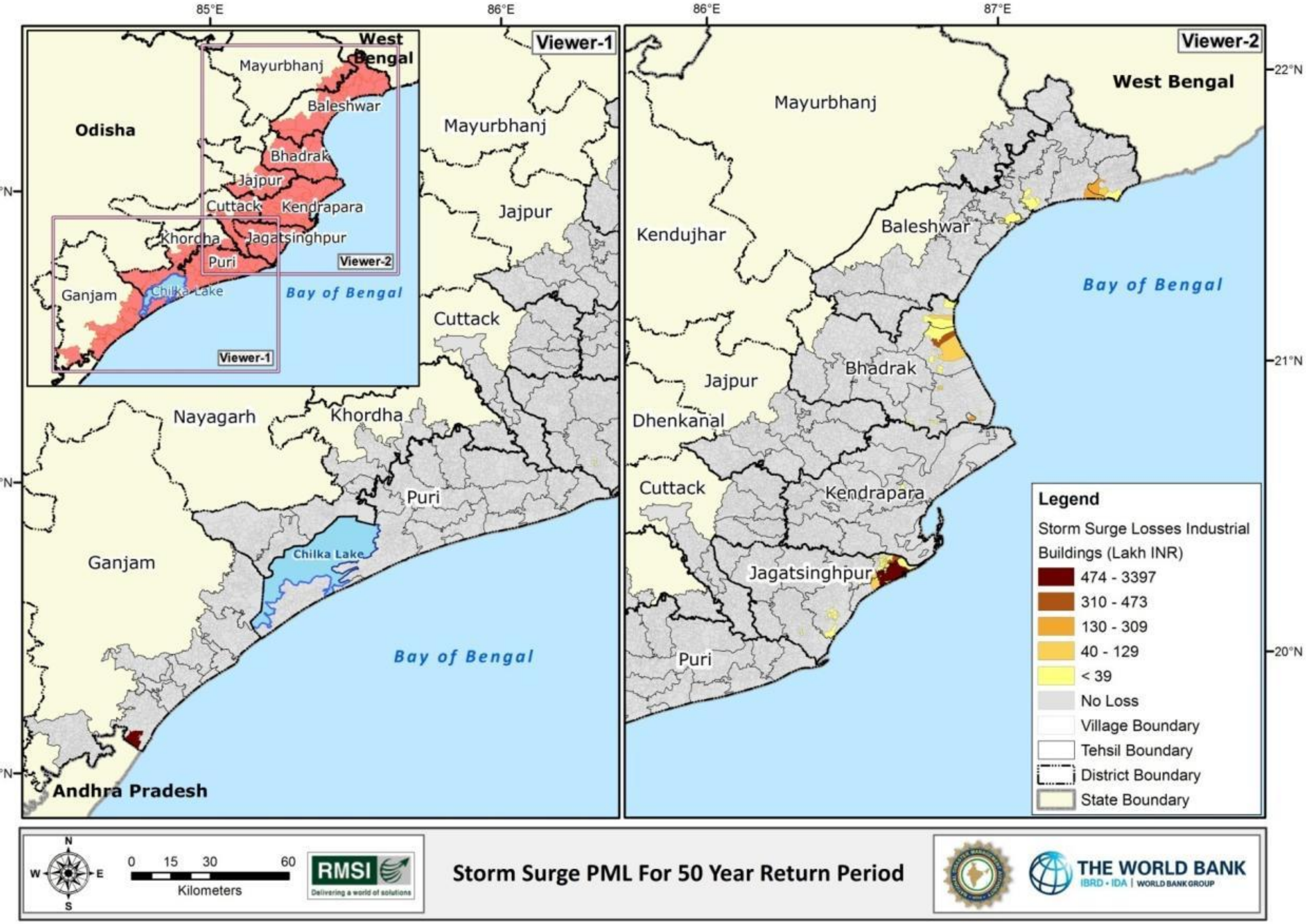

Figure 6-47: PML of industrial buildings due to storm surge for a 50-year return period scenario, Odisha

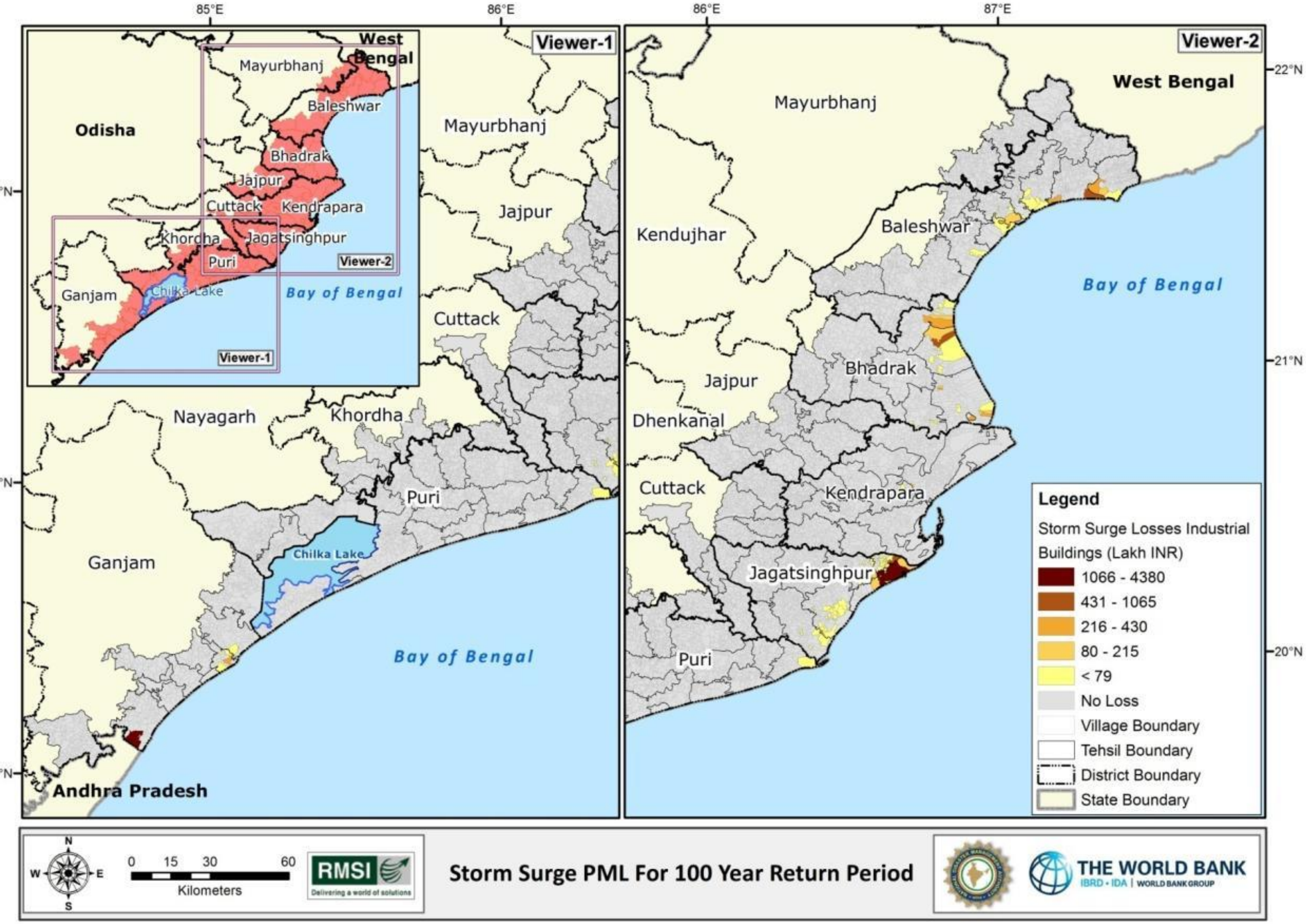

Figure 6-48: PML of industrial buildings due to storm surge for a 100-year return period scenario, Odisha

6.4.3 PML Maps for Cyclone Induced Rainfall Flood

The residential, commercial, and industrial building losses for various probabilistic scenarios (10, 50, and 100 year return periods) for Odisha are given from Figure 6-49 to Figure 6-57. The coastal areas of Baleshwar, Bhadrak, Kendrapara, Jajpur and Jagatsinghpur districts are likely to be affected more for Residential, Commercial and Industrial building exposure. The losses in Kendrapara, Bhadrak and Jajpur are mainly driven by cyclone induced rainfall flood hazard as these areas are severely affected due to flooding whereas the losses in Puri and Jagatsinghpur are mainly driven by their higher exposure.

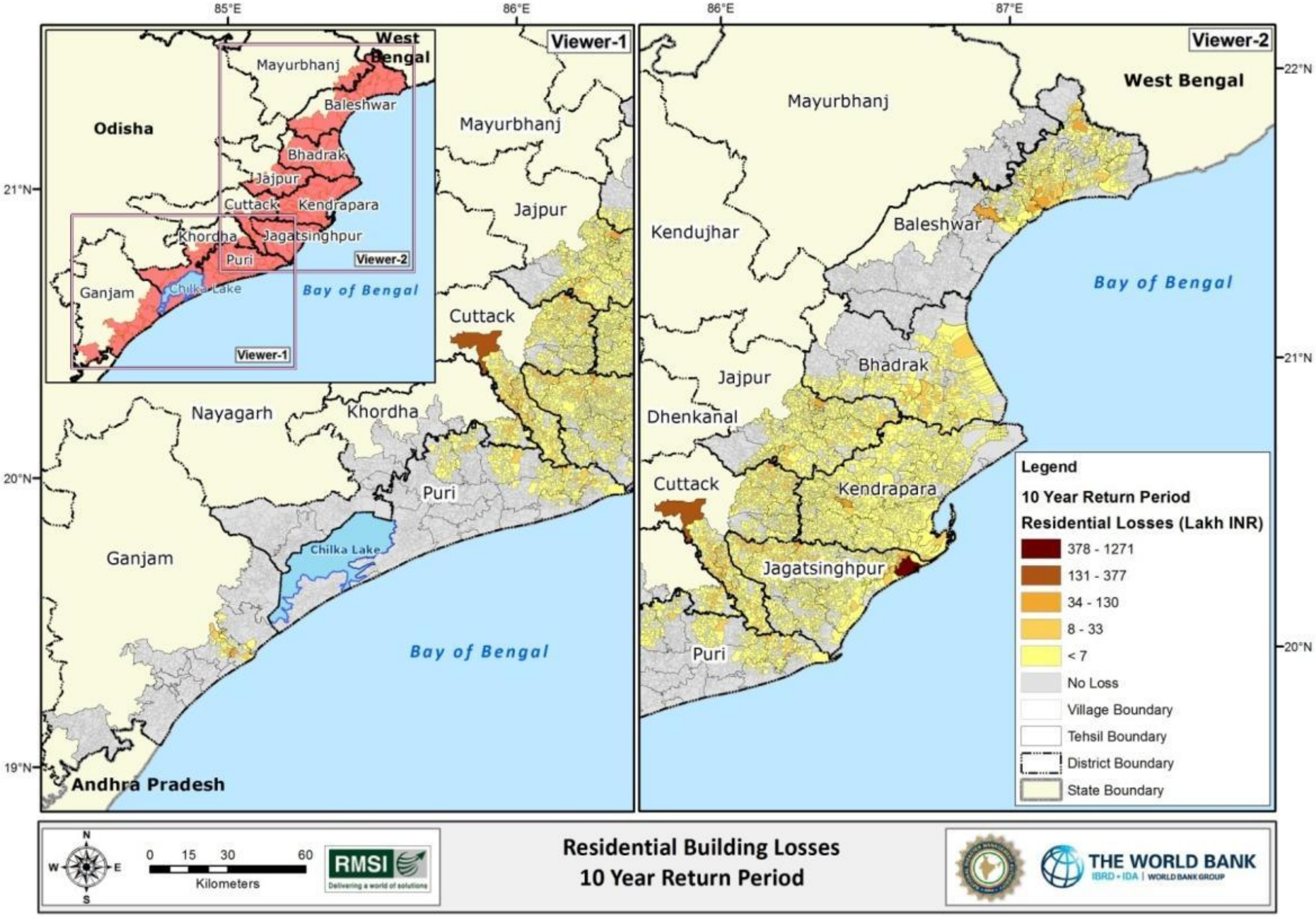

Figure 6-49: PML of residential buildings due to cyclonic rainfall induced flood for a 10-year return period scenario, Odisha

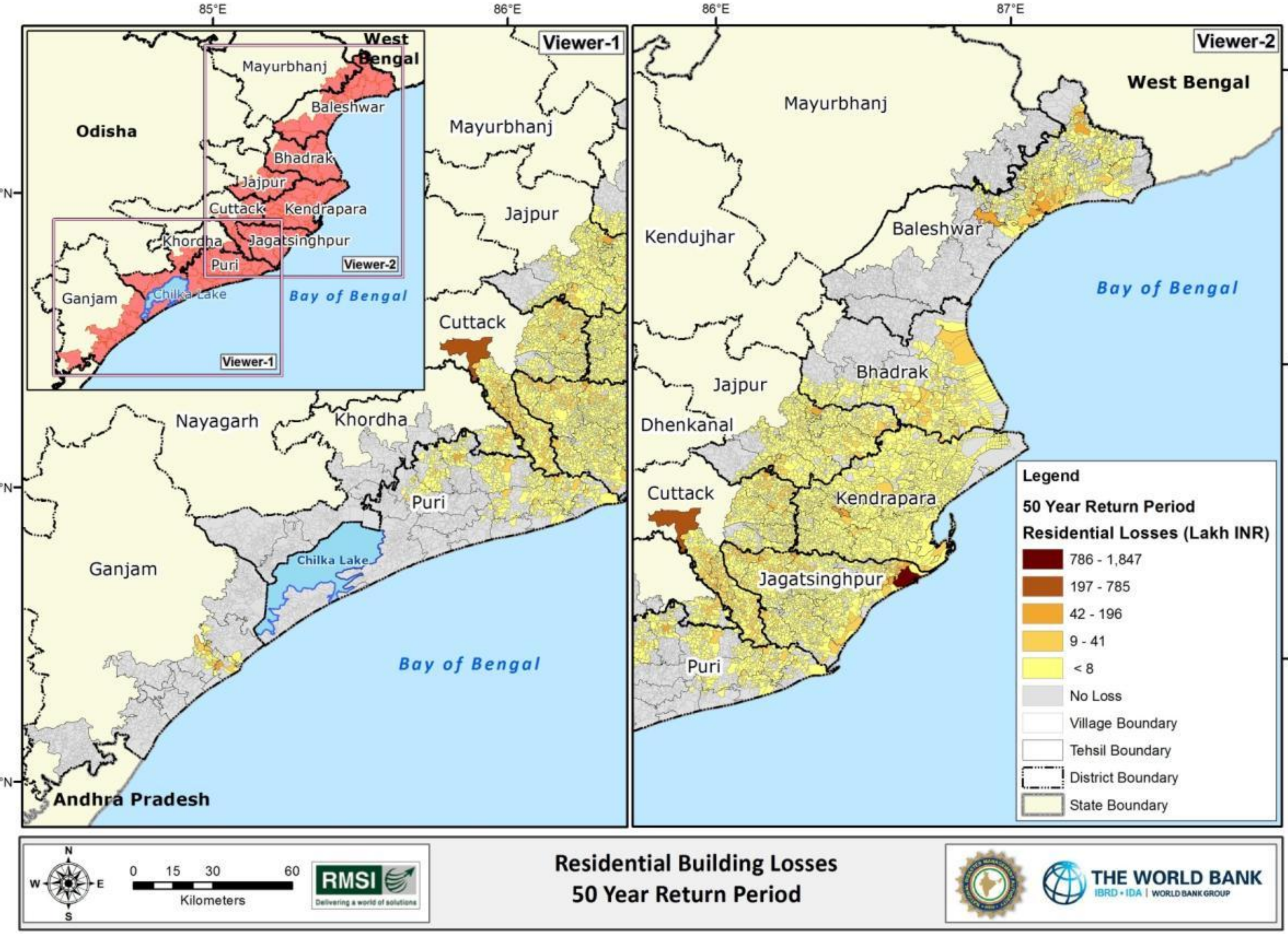

Figure 6-50: PML of residential buildings due to cyclonic rainfall induced flood for a 50-year return period scenario, Odisha

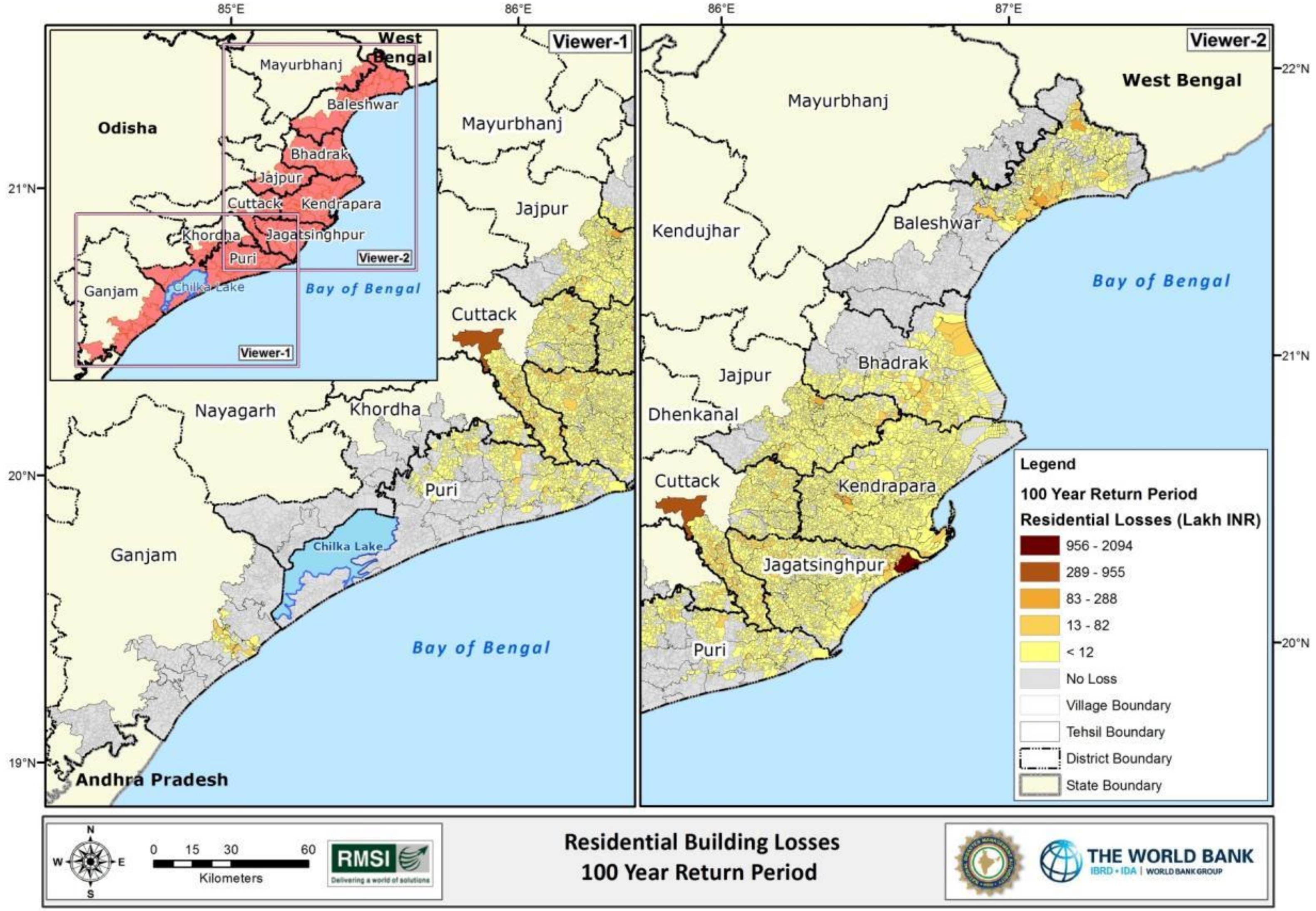

Figure 6-51: PML of residential buildings due to cyclonic rainfall induced flood for a 100-year return period scenario, Odisha

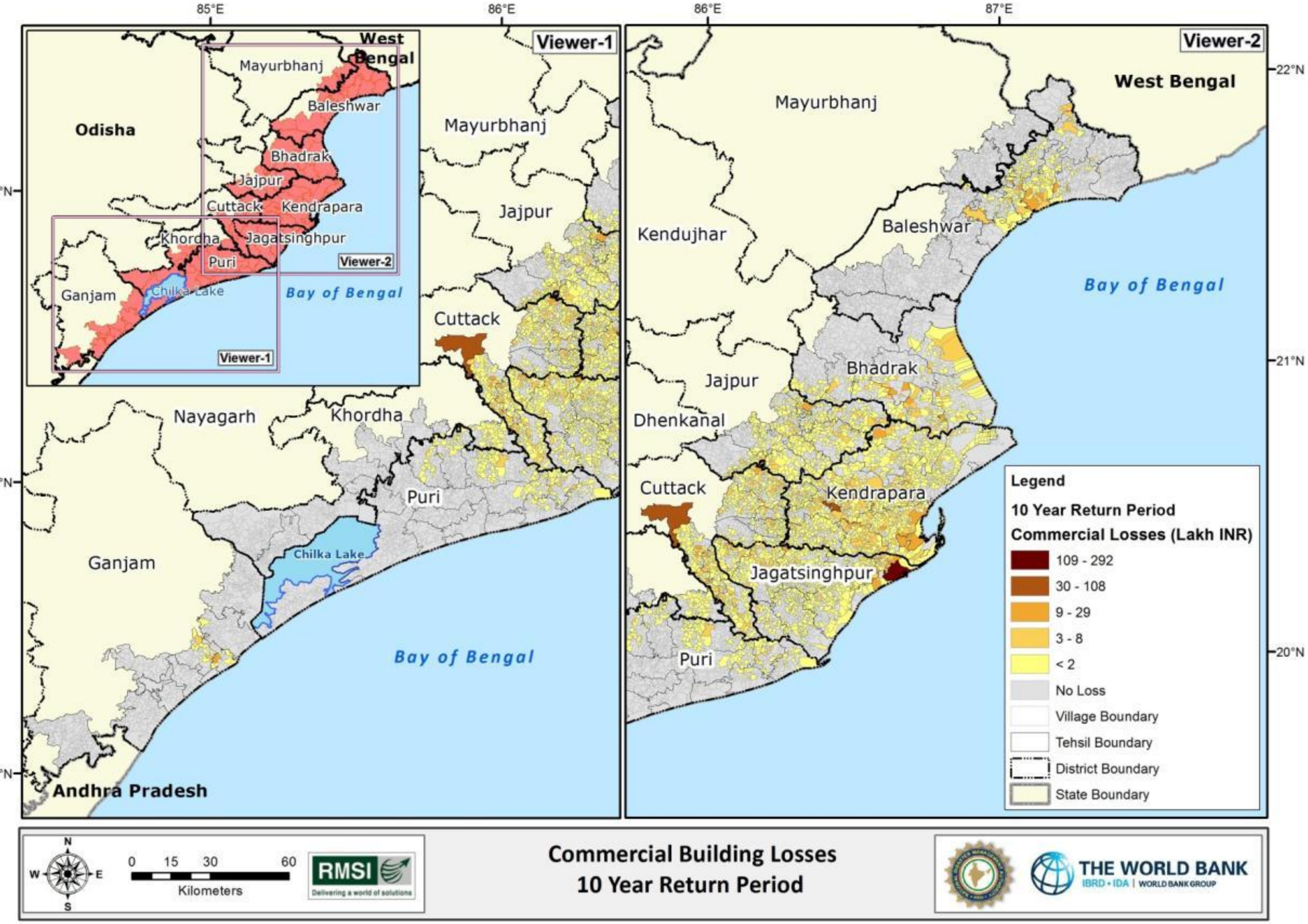

Figure 6-52: PML of commercial buildings due to cyclonic rainfall induced flood for a 10-year return period scenario, Odisha

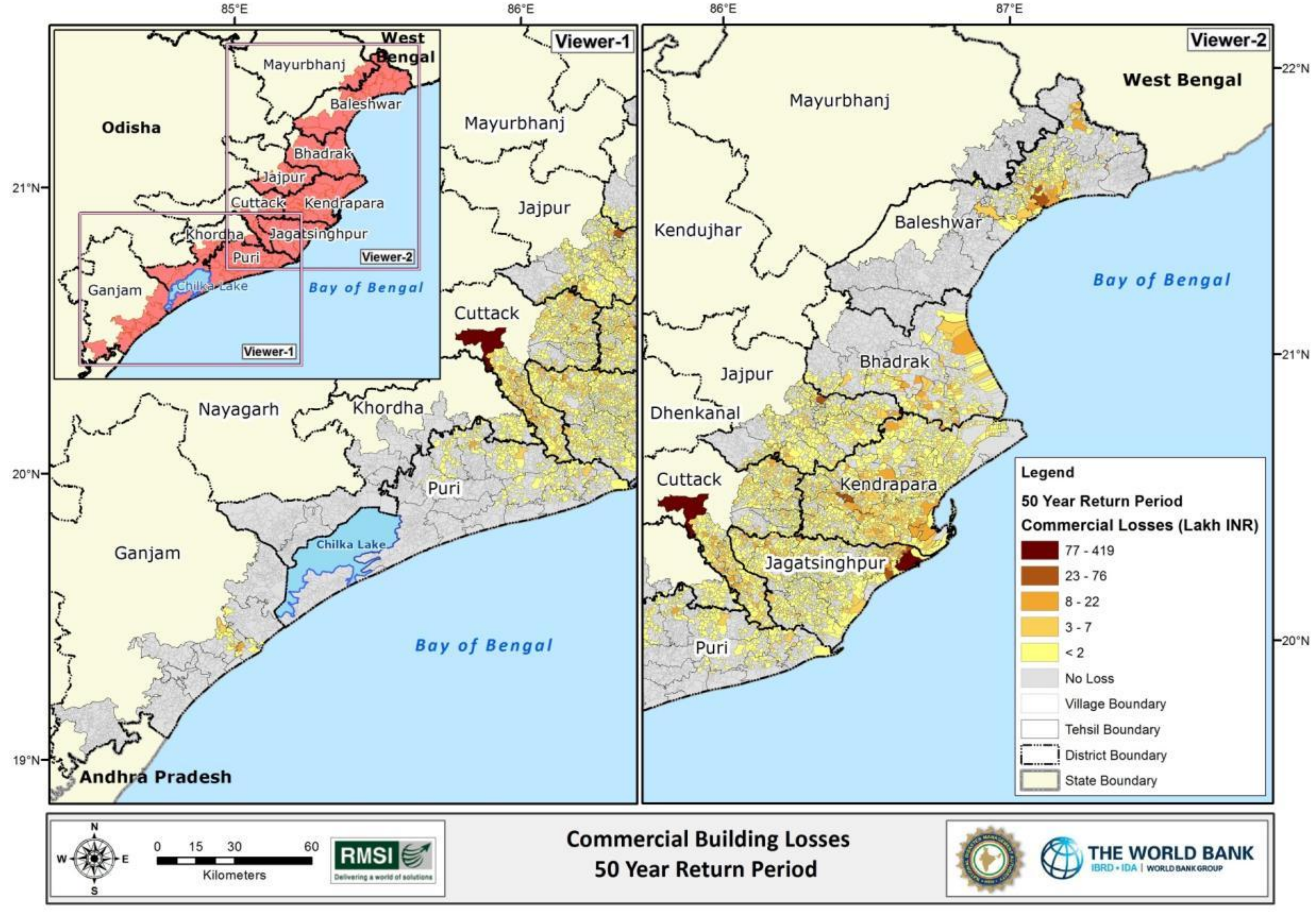

Figure 6-53: PML of commercial buildings due to cyclonic rainfall induced flood for a 50-year return period scenario, Odisha

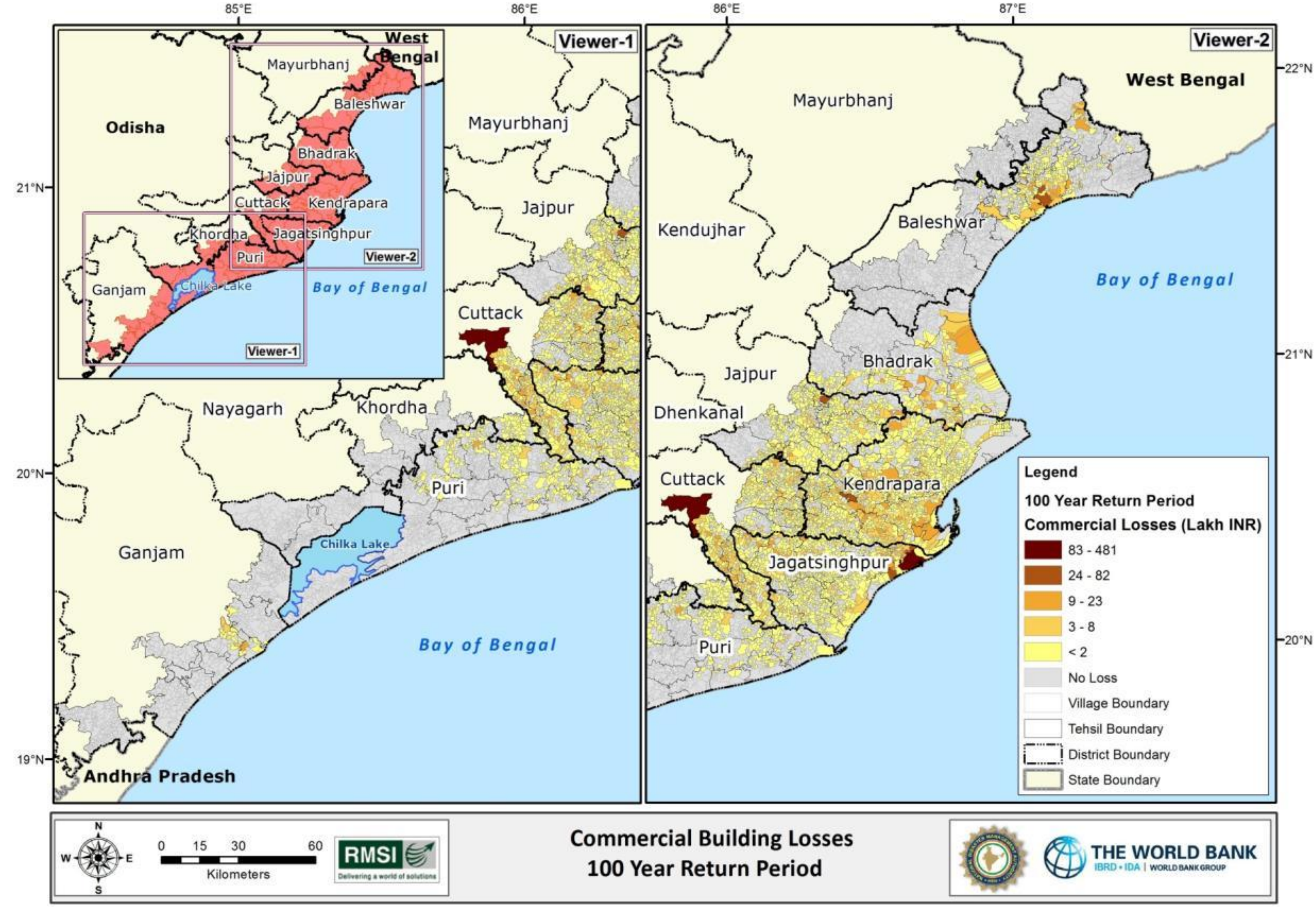

Figure 6-54: PML of commercial buildings due to cyclonic rainfall induced flood for a 100-year return period scenario, Odisha

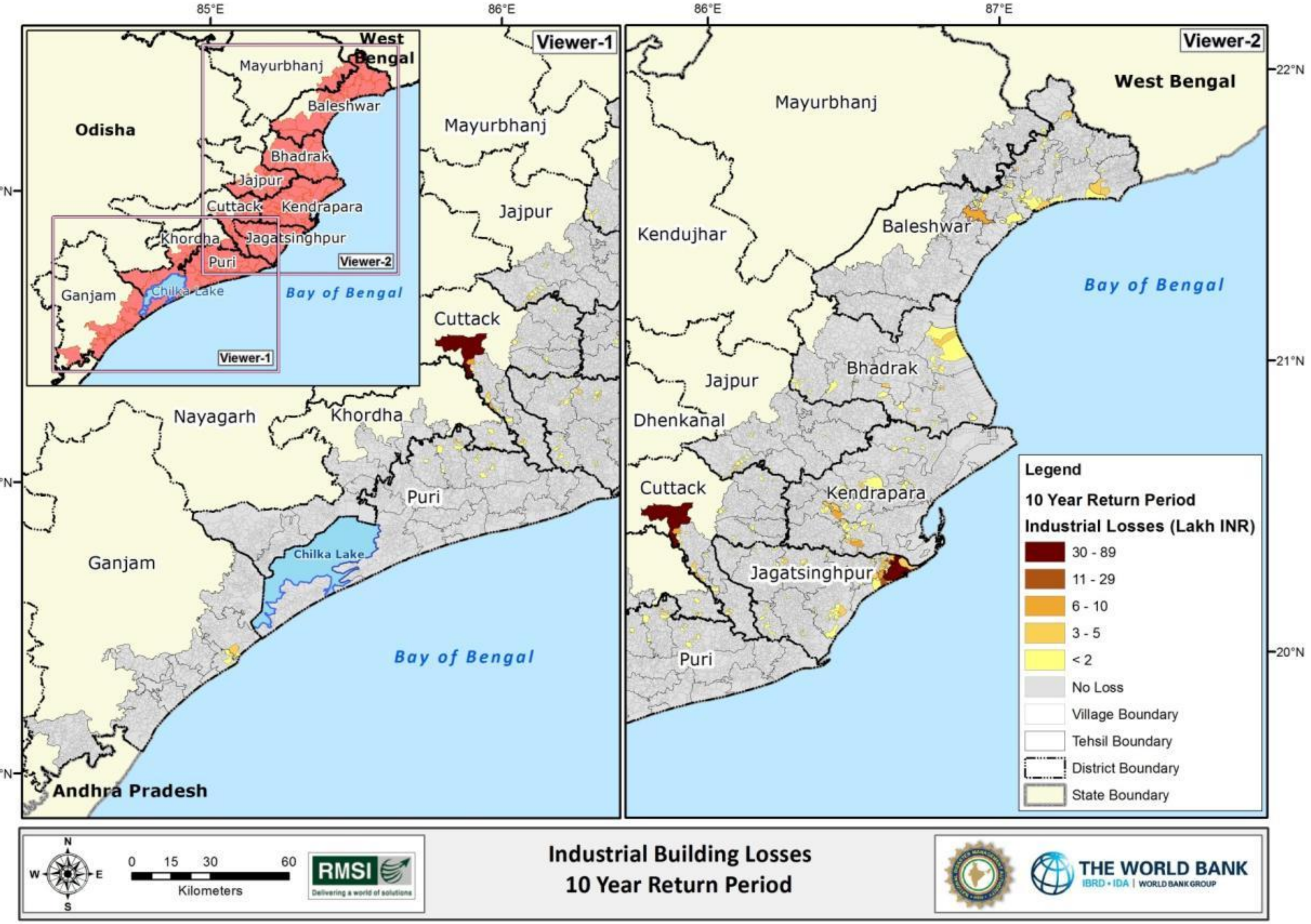

Figure 6-55: PML of industrial buildings due to cyclonic rainfall induced flood for a 10-year return period scenario, Odisha

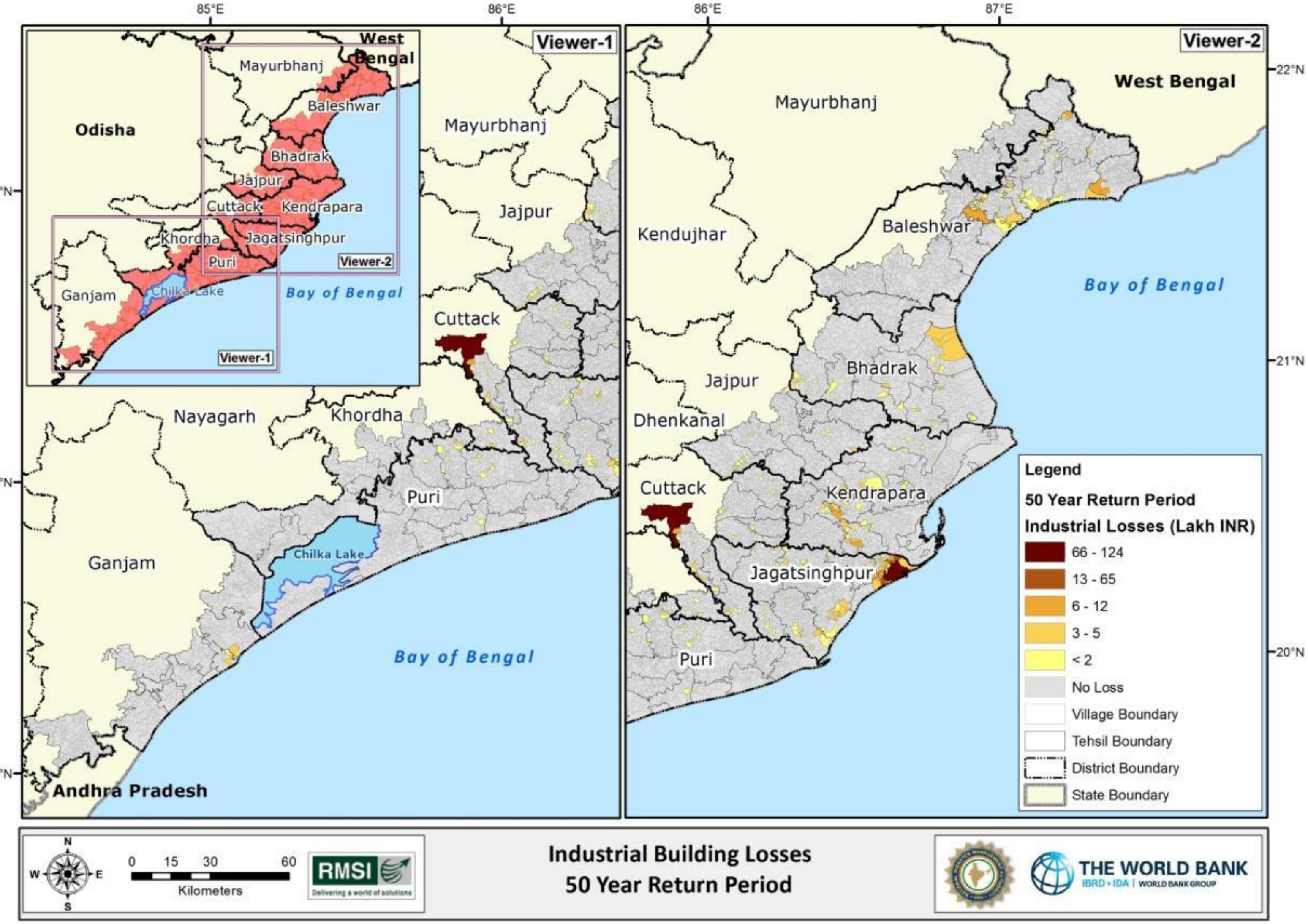

Figure 6-56: PML of industrial buildings due to cyclonic rainfall induced flood for a 50-year return period scenario, Odisha

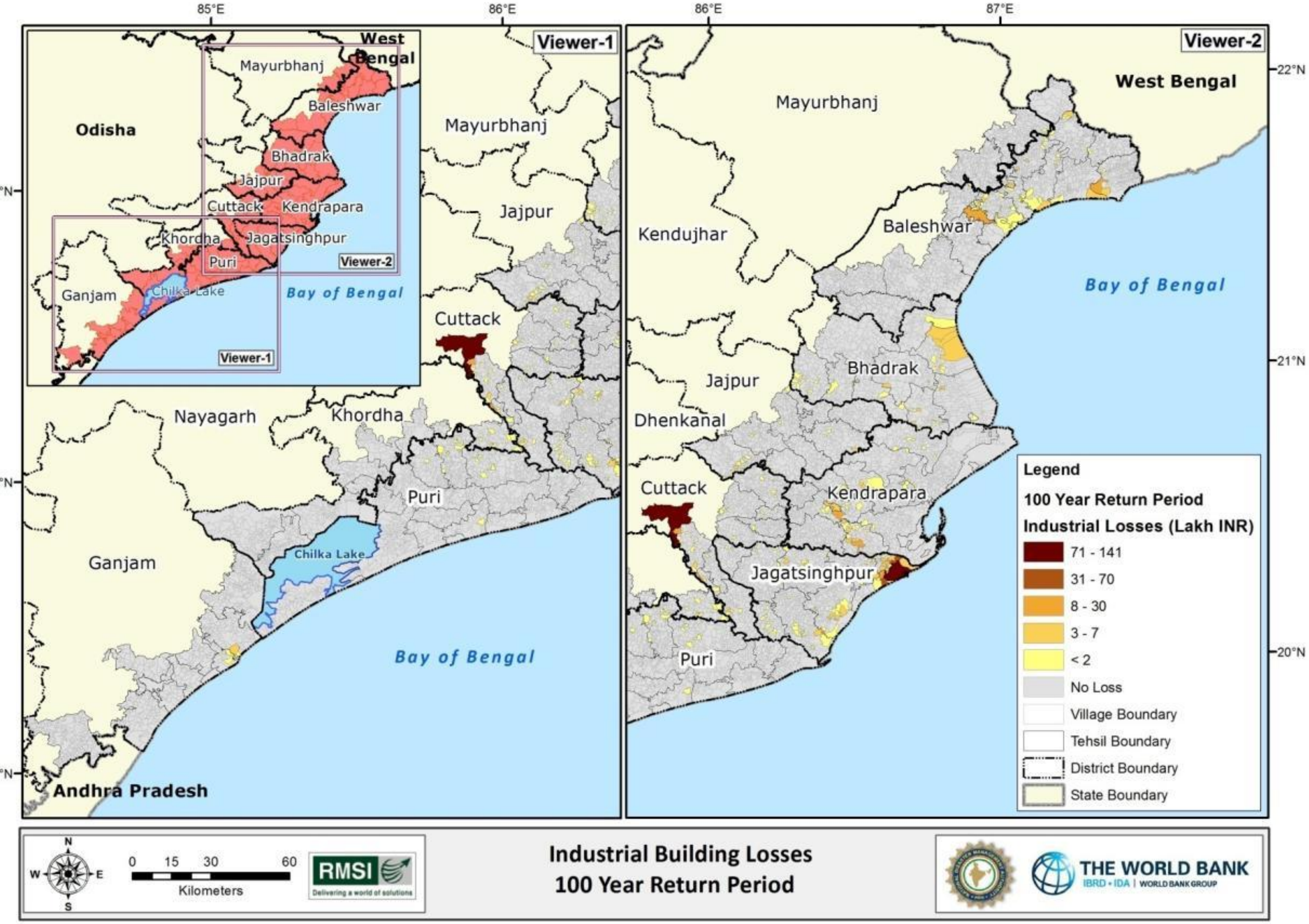

Figure 6-57: PML of industrial buildings due to cyclonic rainfall induced flood for a 100-year return period scenario, Odisha

6.4.4 Composite Loss Maps for Odisha

The composite loss maps for Odisha have been prepared by aggregating the PML due to cyclonic wind, storm surge and cyclonic rainfall induced flood for different return periods.

The residential, commercial, and industrial building composite losses for 100-year return period scenario are given from Figure 6-58 to Figure 6-60. The residential composite loss maps depict that coastal areas of Jagatsinghpur, Ganjam, Cuttack, Puri and Baleshwar districts are more likely to be affected as compared to other districts. The composite losses for commercial buildings in Jagatsinghpur, Cuttack and Kendrapara districts are more likely to be affected as compared to other districts, whereas the industrial composite losses are likely to be more in Jagatsinghpur, Ganjam and Baleshwar districts.

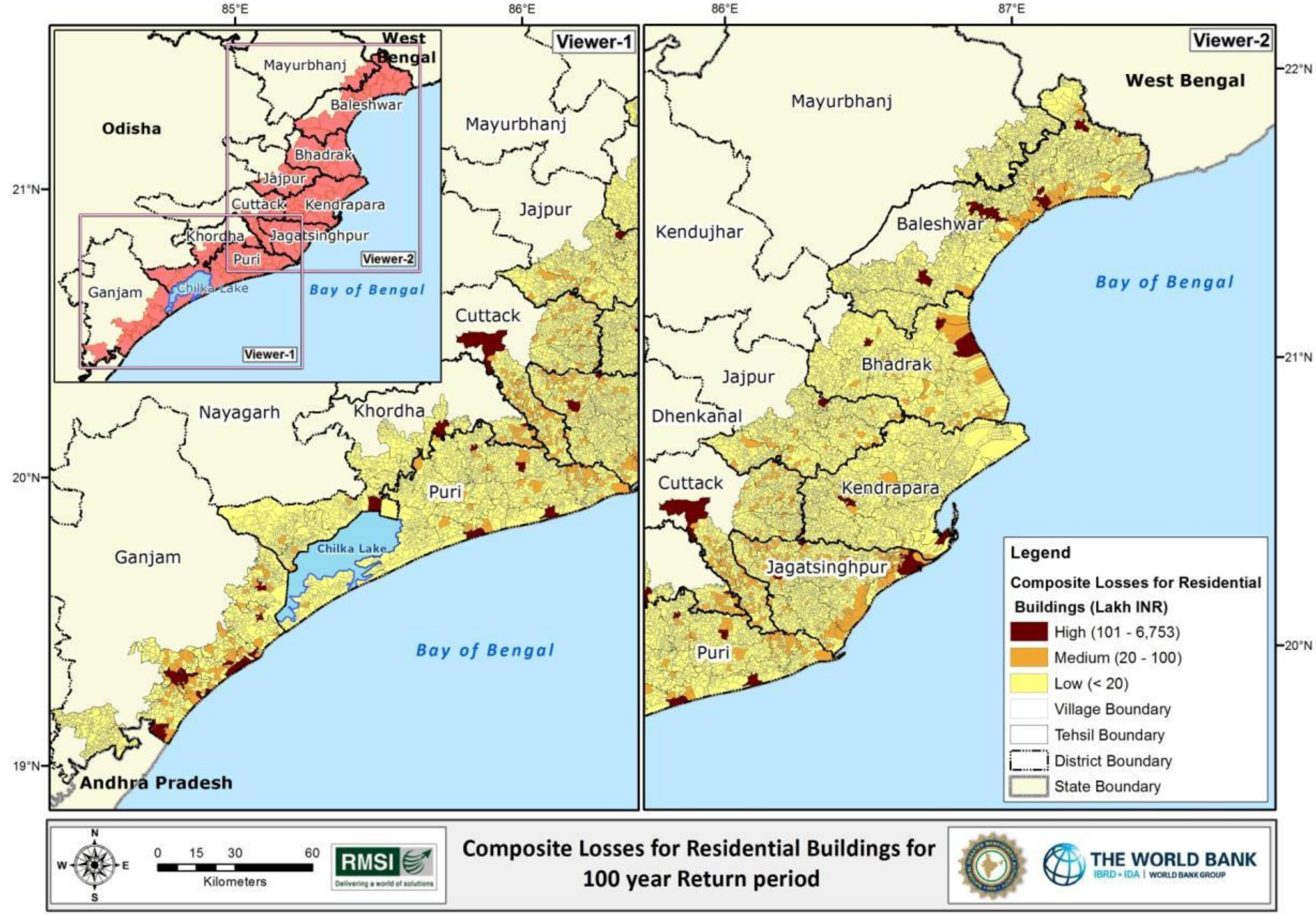

Figure 6-58: Composite losses for residential buildings for a 100-year return period scenario, Odisha

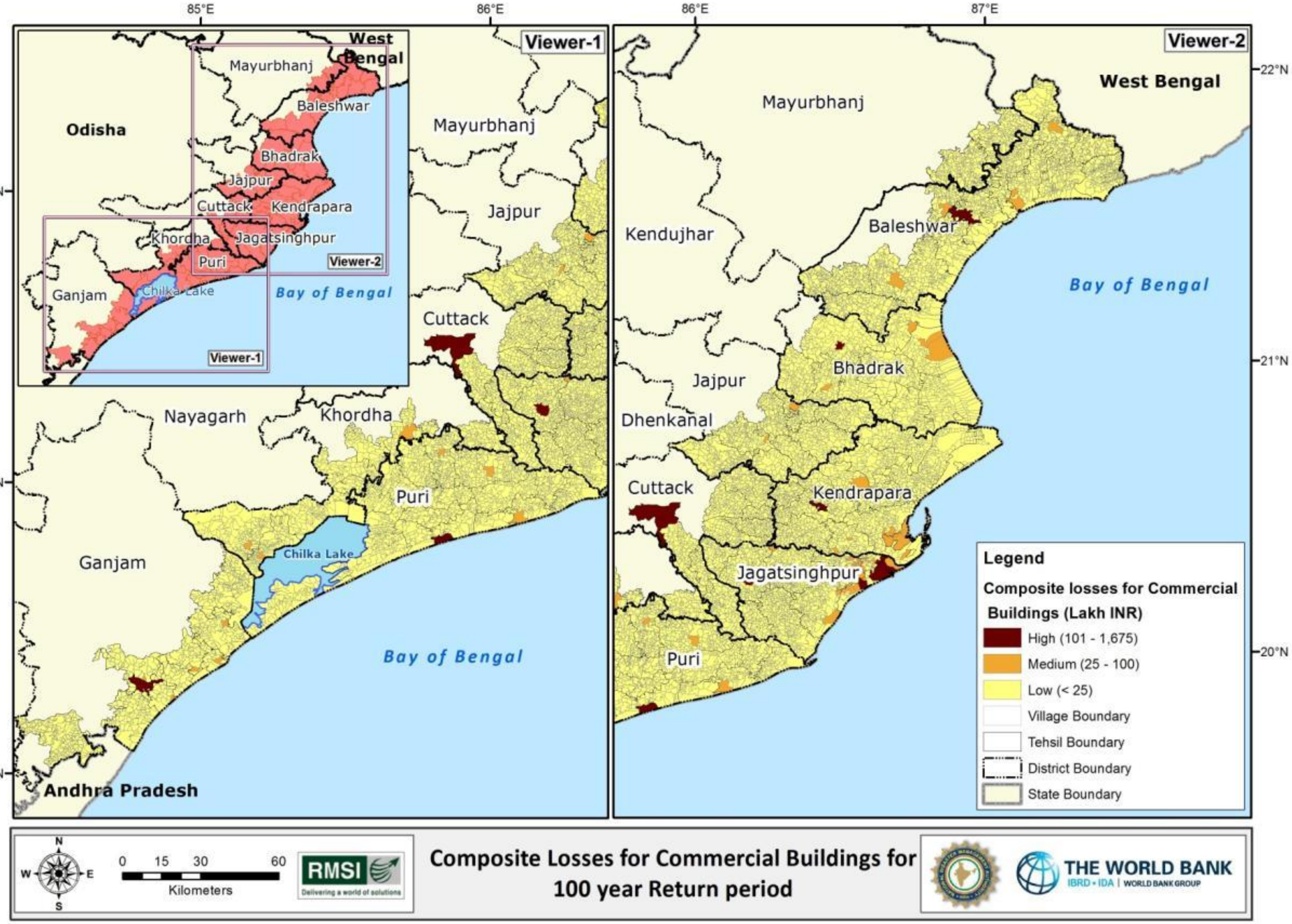

Figure 6-59: Composite losses for commercial buildings for a 100-year return period scenario, Odisha

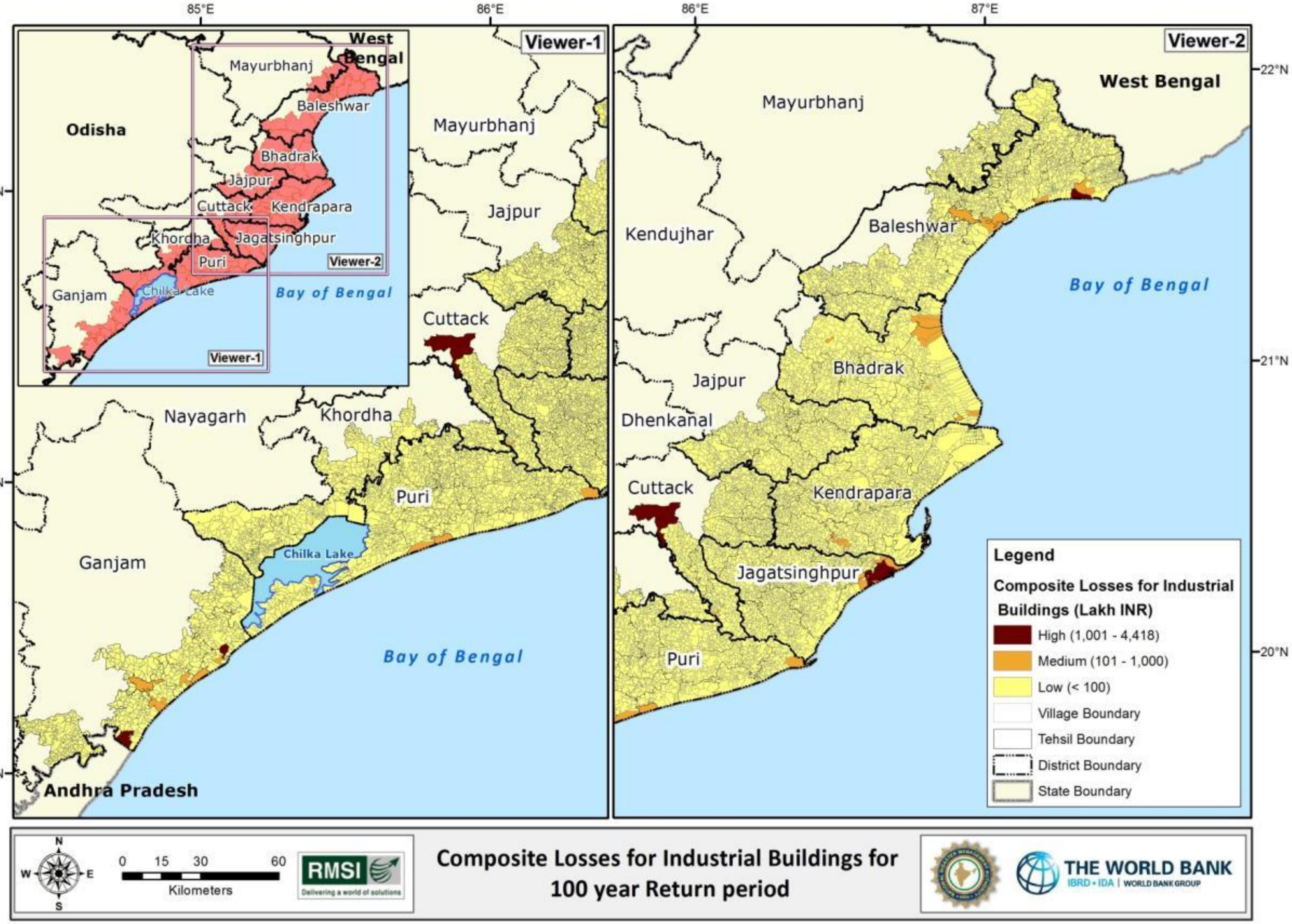

Figure 6-60: Composite losses for industrial buildings for a 100-year return period scenario, Odisha

6.5 Shelter Need Assessment

6.5.1 SHELTER NEED ASSESSMENT FOR ANDHRA PRADESH

As per the methodology explained in section 5.3, shelter need assessment at village-level was carried out and the shelter needs for coastal districts of Andhra Pradesh were prepared. These are presented in Figure 6-61. There are several villages, which have highly vulnerable populations that have a potential to get affected especially since they have an inadequate number of shelters. Guntur, Krishna, and West Godavari districts have the highest requirement for shelters while Srikakulam, Prakasam, and East Godavari districts need relatively lower number of shelters.

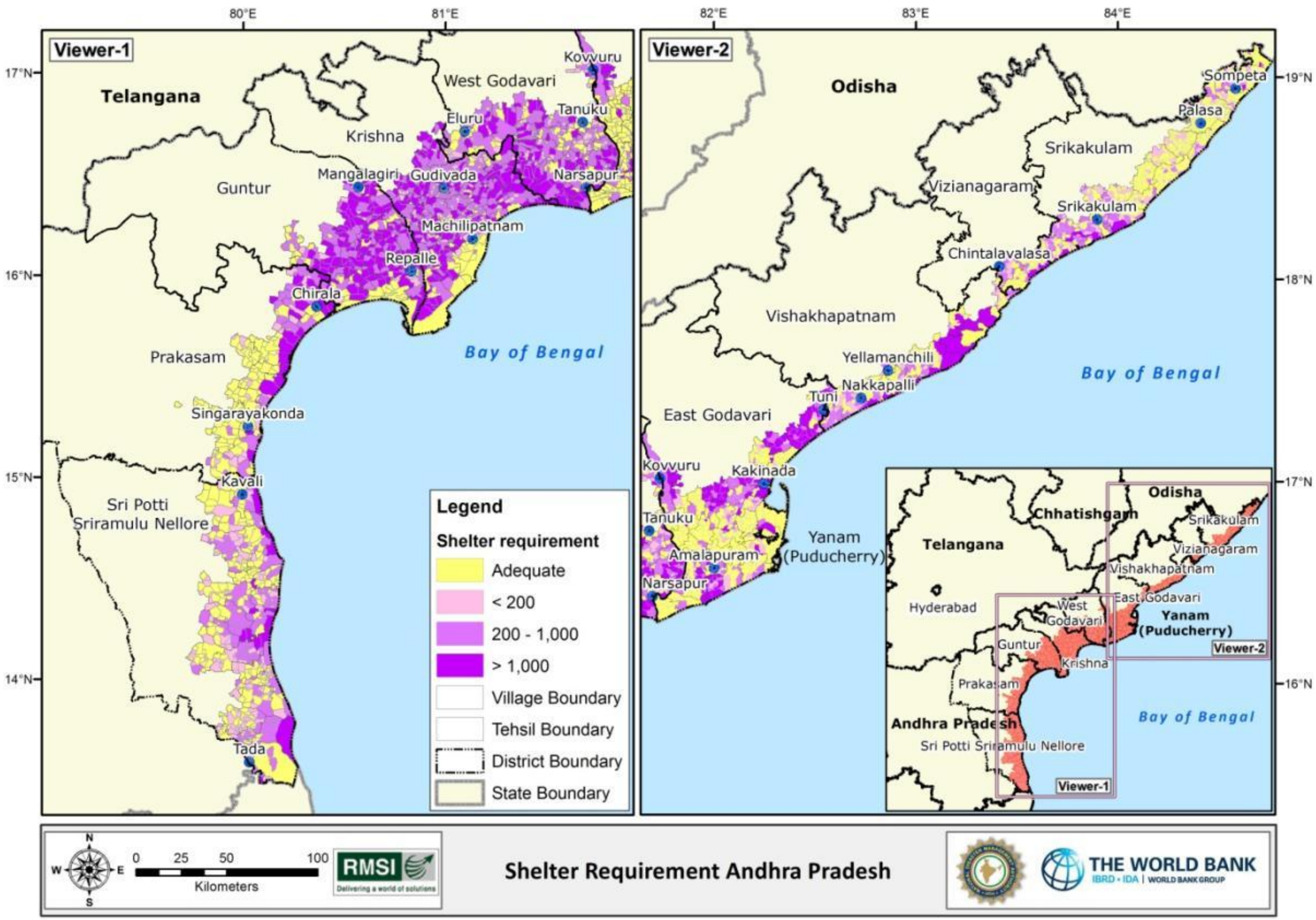

Figure 6-61: Shelter need assessment, Andhra Pradesh

Table 6-5 provides details of the top ten villages/urban areas based on the number of people requiring shelters.

Table 6-5: Shelter need: top ten villages/urban areas based on population that need shelter, Andhra Pradesh

District	Taluk	Village/urban area	Population required shelter
Prakasam	Chirala	Ipuru Palem (Part)	7,704
Vishakhapatnam	Pedagantyada	GVMC (Part)	10,967
	Gajuwaka	GVMC (Part)	15,672
	Pendurti	GVMC (Part)	9,095
	Visakhapatnam (Rural)	GVMC (Part)	35,914
East Godavari	Tuni	S. Annavaram (R)	6,236
	Rajahmundry Urban	Rajahmundry (M Corp. + OG) (Part)	106,180
	Anaparthi	Anaparthy	6,885
	Rajahmundry Rural	Katheru (CT)	6,716
	Kakinada (urban)	Kakinada (M Corp. + OG) (Part)	9,129

6.5.2 SHELTER NEED ASSESSMENT FOR ODISHA

The shelter needs for the coastal districts of Odisha are presented in Figure 6-62. Odisha coastal districts provide quite different picture as compared to Andhra Pradesh. While considering the schools and religious places along with the cyclone and flood shelters, most of the districts, in general, have adequate shelters except for Mayurbhanj district. However, while analyzing at the village level, there are several villages in Puri, Cuttack, Jagatsinghpur, and Bhadrak districts, which need shelters to support a potential affected population of more than 200 people.

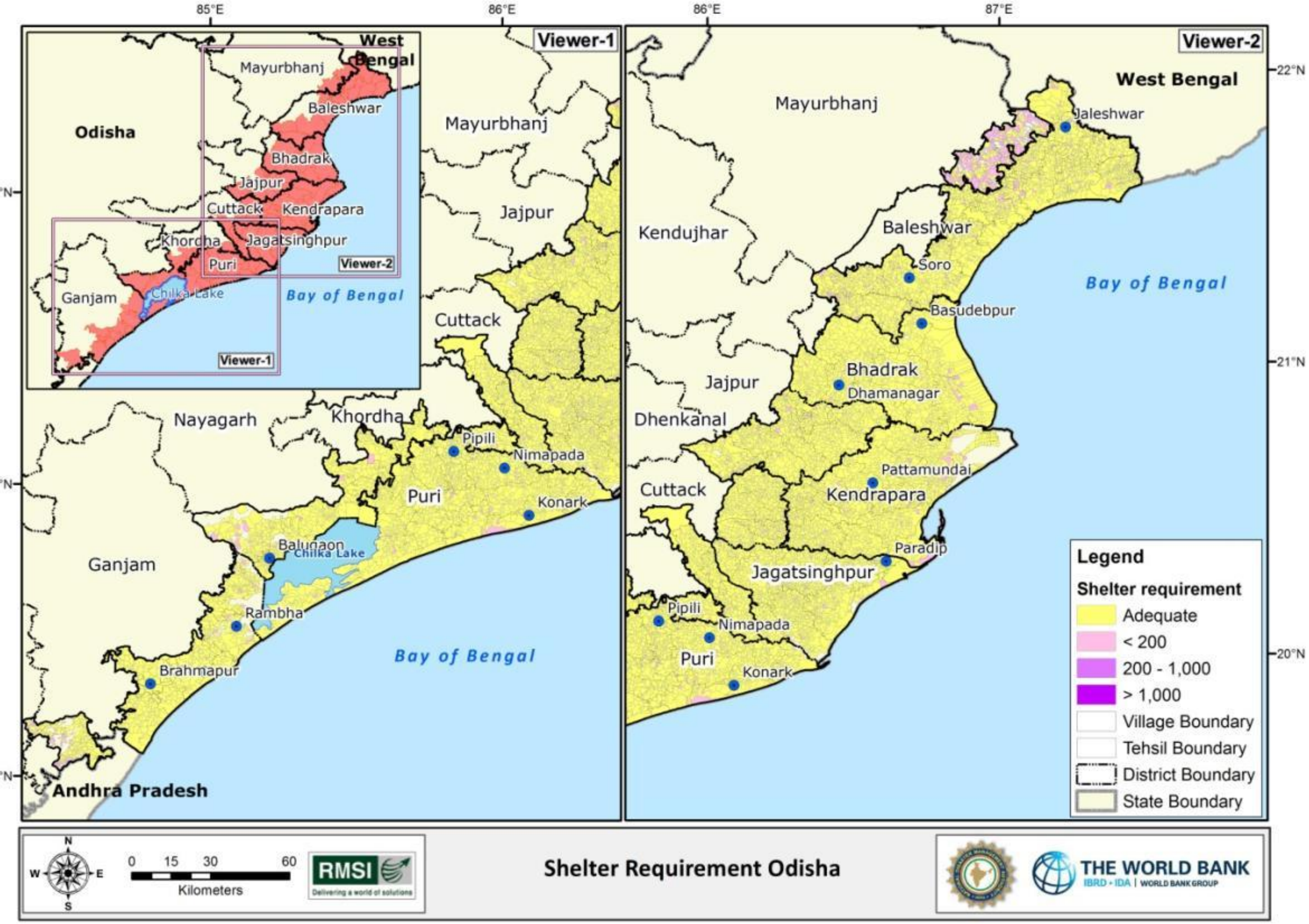

Figure 6-62: Shelter need assessment, Odisha

The Table 6-6 provides details of the top ten villages/urban areas based on the number of people requiring shelters.

Table 6-6: Shelter need: top ten villages/urban areas based on population that need shelters, Odisha

District	Taluka	Villages/urban areas	Population requiring shelters
Mayurbhanj	Rasagobindapur	Jhatiapada	121
		Nunchati	126
		Deosul	102
		Sansa	89
		Dhansul	124
	Baisinga	Raikama	90
		Purunapani Samil Kakharu Khunt	89
		Khadikapada	98
		Ambagadia	88
		Manatri	114
		Gadadeulia	141

6.6 Hotspot Identification

6.6.1 HOTSPOT VILLAGES OF ANDHRA PRADESH

It is observed in Andhra Pradesh that:

- None of the villages have high vulnerability to all three hazards
- Flood + Wind high for 19 villages
- Wind + Surge high for 90 villages
- Flood+ Surge high for 6 villages

The Figure 6-63 shows the locations of hotspots in Andhra Pradesh. Majority of the hotspot locations are located in Krishna and Vishakhapatnam districts while the rest are located in Vizianagaram and Srikakulam districts.

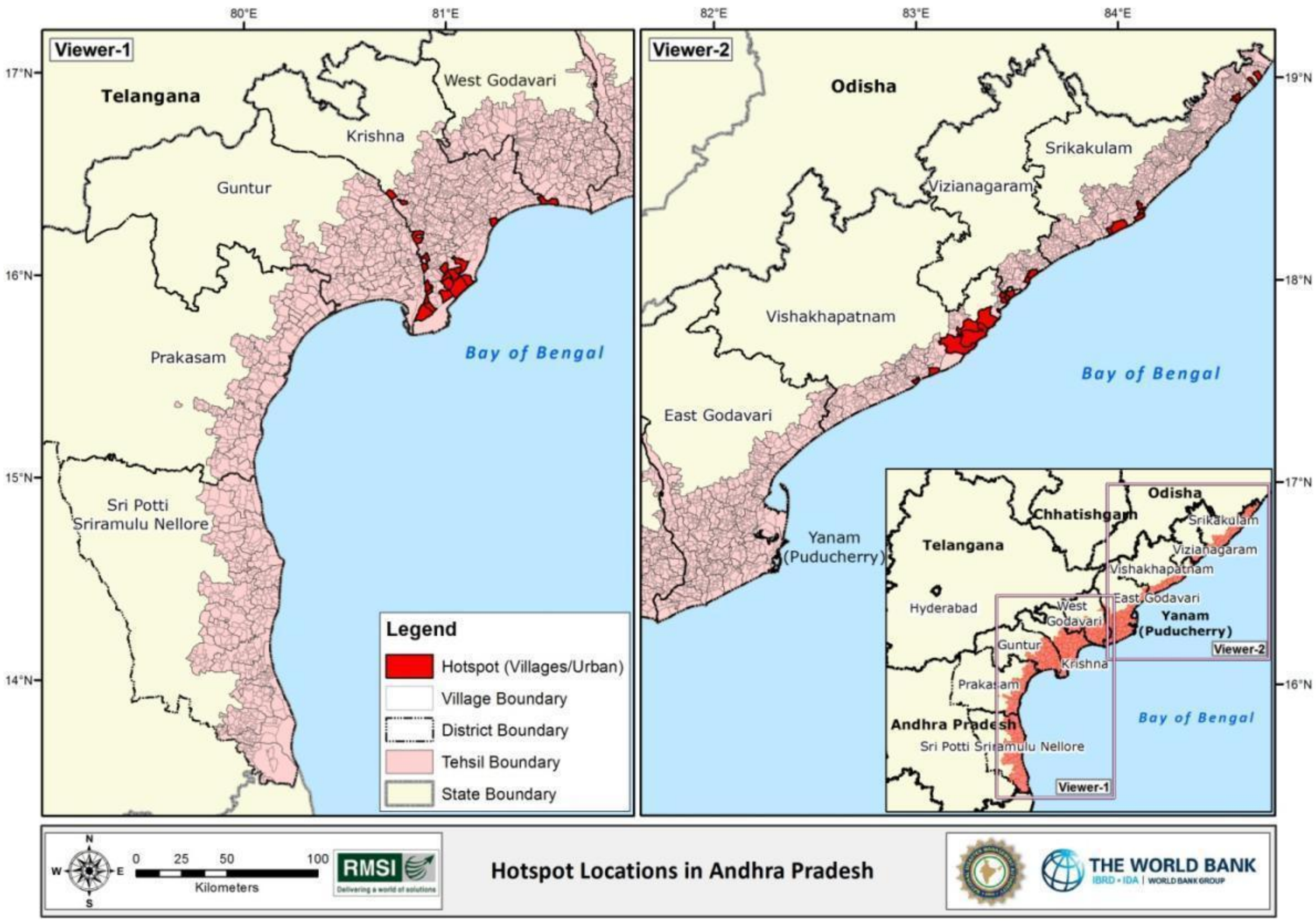

Figure 6-63: Hotspot locations in Andhra Pradesh

The Table 6-7 provides the details of villages identified as hotspot locations along with priority ranking based on high hazard values, SOVIs and shelter needs in Andhra Pradesh.

Table 6-7: Villages/urban areas identified as hotspots in Andhra Pradesh

District	Tehsil	Village	Area type	Priority Ranking
Krishna	Nagayalanka	T.Kothapalem	Rural	1
Krishna	Koduru	Ramakrishnapuram	Rural	2
Krishna	Koduru	Koduru	Rural	3
Krishna	Koduru	Mandapakala	Rural	4
Krishna	Mopidevi	Kokkiligadda	Rural	5
Krishna	Machilipatnam	Tallapalem	Rural	6
Krishna	Nagayalanka	Nagayalanka	Rural	7
Krishna	Avanigadda	Puligadda	Rural	8
Krishna	Ghantasala	Srikakulam	Rural	9
Krishna	Koduru	Ullipalem	Rural	10
Krishna	Nagayalanka	Edurumondi	Rural	11
Krishna	Nagayalanka	Kammanamolu	Rural	12
Srikakulam	Kaviti	Borivanka	Rural	13
Srikakulam	Kaviti	Kaviti	Rural	14
Srikakulam	Sompeta	Baruvapeta	Rural	15
Srikakulam	Vajrapukotturu	Laxmidevipeta Nuvvalarevu	Rural	16
Krishna	Machilipatnam	Pedayadara	Rural	17
Srikakulam	Gara	Thonangi	Rural	18
Srikakulam	Sompeta	Baruva	Rural	19
Srikakulam	Gara	Srikurmam	Rural	20
Srikakulam	Gara	Calingapatnam	Rural	21
Krishna	Totlavalluru	North Valluru	Rural	22
Vishakhapatnam	Achchutapuram	Pudimadaka	Rural	23
Vizianagaram	Bhogapuram	Kongavanipalem	Rural	24
Krishna	Koduru	Lingareddipalem	Rural	25
Krishna	Koduru	Viswanadhapalle	Rural	26
Krishna	Nagayalanka	Etimoga	Rural	27
Vishakhapatnam	Bhimunipatnam	Bheemunipatnam (M + OG)	Urban	28
Vishakhapatnam	Bhimunipatnam	Chepalappada	Rural	29
Vizianagaram	Pusapatirega	Konada	Rural	30
Vishakhapatnam	Visakhapatnam (Rural)	GVMC (Part)	Urban	31
Vishakhapatnam	Gajuwaka	GVMC (Part)	Urban	32
Vishakhapatnam	Visakhapatnam (Urban)	GVMC (Part)	Urban	33
Krishna	Kruttivennu	Chinagollapalem	Rural	34
Vishakhapatnam	Bhimunipatnam	Mulakuddu (CT)	Urban	35
Srikakulam	Srikakulam	Ippili	Rural	36
Vishakhapatnam	Bhimunipatnam	Chippada	Rural	37

District	Tehsil	Village	Area type	Priority Ranking
Vishakhapatnam	Paravada	Cheepurupalle (East)	Rural	38
Krishna	Kankipadu	Madduru	Rural	39
Srikakulam	Polaki	Polaki	Rural	40

6.6.2 HOTSPOT VILLAGES OF ODISHA

It is observed in Odisha that:

- 33 villages have high vulnerability to all three hazards
- However, none of them have corresponding high 'Exposure and SoVI' indexes.

Figure 6-64 presents the distribution of hotspots in Odisha. These are mostly distributed in Puri, Cuttack, Jagatsinghpur, and Baleshwar districts.

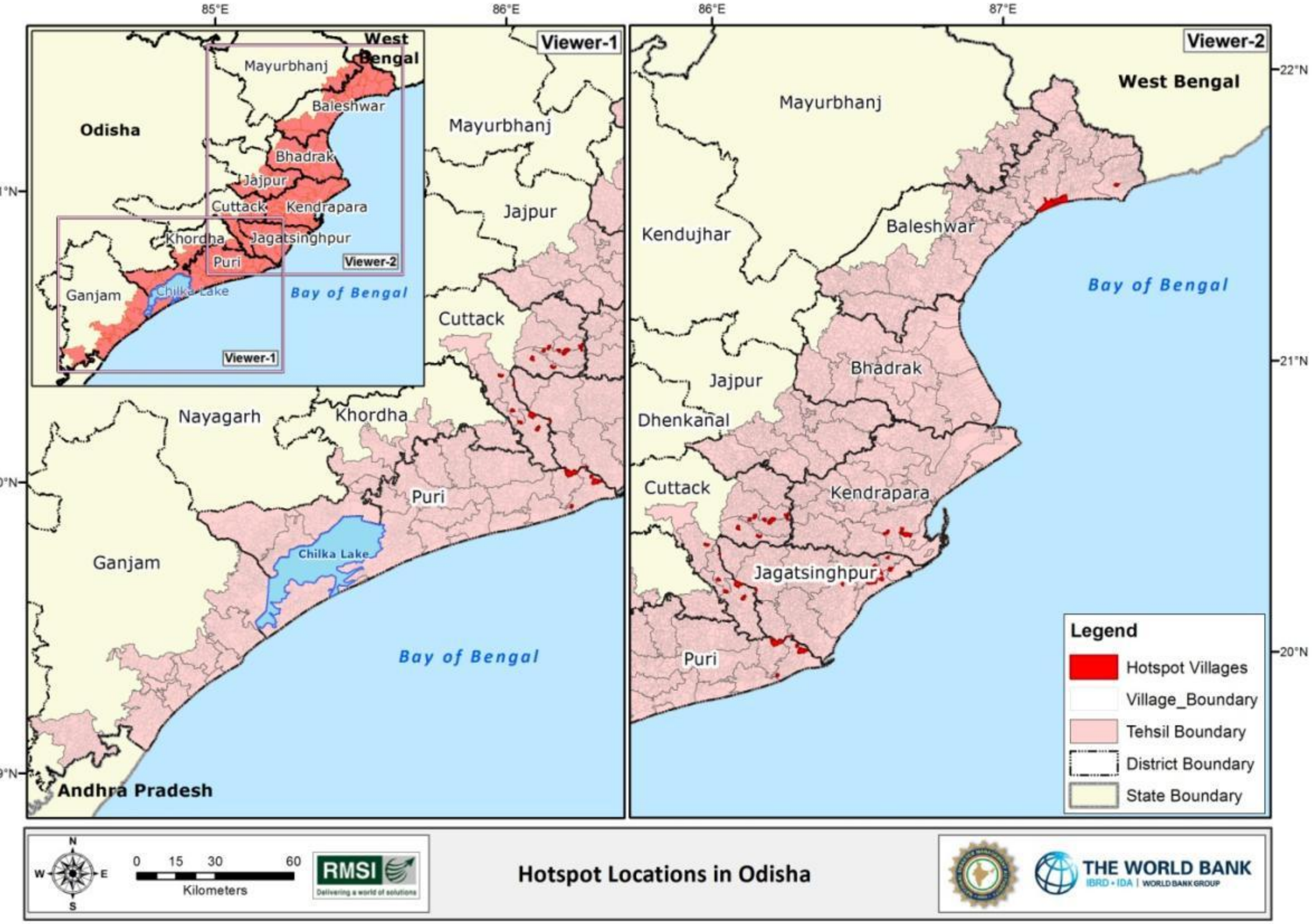

Figure 6-64: Hotspot locations in Odisha

Table 6-8 provides details of the villages identified as hotspot locations along with priority ranking based on high hazard values, SOVI, and shelter needs in Odisha.

Table 6-8: Villages/Urban areas identified as hotspots in Odisha

District	Tehsil	Village	Area type	Priority Ranking
Puri	Astaranga	Patasundarpur	Rural	1
Puri	Astaranga	Badasirei	Rural	2
Puri	Astaranga	Nagar	Rural	3
Cuttack	Nemalo	Baliapada	Rural	4
Baleshwar	Bhograi	Rankotha	Rural	5
Cuttack	Nemalo	Janardanpur	Rural	6
Cuttack	Nischintakoili	Kulagan-isalo	Rural	7
Cuttack	Gobindpur	Gobindpur	Rural	8
Cuttack	Salepur	Khandagan	Rural	9
Cuttack	Cuttack Sadar	Kulasarichuan	Rural	10
Cuttack	Kishannagar	Kesannagar	Rural	11
Cuttack	Gobindpur	Manikunda	Rural	12
Baleshwar	Baliapal	Jambhirai	Rural	13
Puri	Kakatpur	Bhandisahi	Rural	14
Jagatsinghpur	Abhyachandpur	Trilochanpur	Rural	15
Jagatsinghpur	Ersama	Mallipur	Rural	16
Cuttack	Niali	Banchhasailo	Rural	17
Baleshwar	Singla (p)	Kasafal	Rural	18
Jagatsinghpur	Kujang	Gandakipur	Rural	19
Cuttack	Nemalo	Tilakana	Rural	20
Cuttack	Niali	Sagadailo	Rural	21
Jagatsinghpur	Kujang	Kankardia	Rural	22
Kendrapara	Mahakalapada	Mangalapur	Rural	23
Jagatsinghpur	Kujang	Fatepur	Rural	24
Cuttack	Kishannagar	Nuagaon	Rural	25
Jagatsinghpur	Paradeep Luck	Pipal	Rural	26
Cuttack	Gobindpur	Gopalnagar	Rural	27
Jagatsinghpur	Kujang	Balitutha	Rural	28
Cuttack	Niali	Kulasri	Rural	29
Jagatsinghpur	Kujang	Kharigotha	Rural	30
Jagatsinghpur	Abhyachandpur	Rangiagarh	Rural	31
Jagatsinghpur	Naugaon	Suakana (suankara)	Rural	32
Kendrapara	Mahakalapada	Baulakani	Rural	33

7 Status of Progress on Web-GIS Risk Atlas Development

Functionality	Sub Functionality	Status	Status as on Oct 23rd 2015
Login Page	Login to application	Done	
	Register to application	Done	
Homepage	Risk Summary of state	Done	
	Map Applications	In process	In process
	View Detailed Risk of state	Done	
	View Detailed Map Applications	In process	In process
Manage Risk Atlas	Manage Risk Map	Done	
	Manage Risk Analysis Map	In process	Done
	Manage Hotspot Map	In process	In process
Manage Exposure	Manage Aggregated Exposure	Done	
	Manage Site-specific Exposure	Done	
	Manage Crop exposure	In process	Done
	Manage Population	In process	Done
	Manage Hotspot Exposure	In process	In process
Manage Vulnerability	Manage Aggregated Vulnerability	Done	
	Manage Site-specific vulnerability	Done	
	Manage crop vulnerability	In process	In process
	Manage population vulnerability	In process	Done
	Manage hotspot vulnerability	In process	In process
Risk Analysis	Submit Analysis	Done	
	Create Analysis Scheduler	Done	
	Write Risk Assessment functions in database	In process	Done
	Design and implementation of Risk analysis report	In process	In process
Hotspot Analysis	Submit Hotspot Analysis	In process	In process
	Create Hotspot Analysis Scheduler	In process	In process
	Write hotspot analysis functions in database	In process	In process
	Design and implementation of Hotspot analysis report	In process	In process
Upload	Upload Layers	Done	
	Upload Document	Done	
User based Accessibility	Admin accessibility	In process	In process
	Registered user accessibility	In process	In process

8 Annexes

8.1 Annex 1: Loss estimates by district

Table 8-1: Distribution of storm surge losses for different occupancy types by districts

District Name	Andhra Pradesh						District Name	Odisha					
Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP	Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP
Residential (Loss in INR Lakhs)													
East Godavari	17.12	19.27	21.12	26.15	34.94	623.25	Baleshwar	7.44	9.22	12.19	30.21	140.95	1,001.01
Guntur	0.27	0.30	0.33	0.38	0.43	4.58	Bhadrak	27.01	36.36	53.47	234.99	788.93	2,457.46
Krishna	0.29	0.36	0.48	0.71	1.01	32.01	Cuttack	-	-	-	-	-	-
Prakasam	18.81	21.96	25.91	29.44	33.57	70.66	Ganjam	3.06	4.67	6.74	11.44	16.96	74.45
Sri Potti Sriramulu Nellore	8.12	19.99	42.36	54.93	103.88	704.54	Jagatsinghpur	0.30	6.70	11.28	1,047.10	2,562.39	7,585.29
Srikakulam	13.14	15.50	16.23	18.90	21.02	26.72	Jajpur	-	-	-	-	-	-
Vishakhapatnam	90.34	101.37	110.12	132.74	167.62	216.16	Kendrapara	0.82	3.52	3.93	110.27	371.85	836.97
Vizianagaram	-	-	-	-	-	0.25	Khordha	-	-	-	-	-	-
West Godavari	0.52	0.56	0.59	0.66	0.76	1.35	Mayurbhanj	-	-	-	-	-	-
							Puri	1.68	1.89	2.04	2.33	2.69	384.26
Commercial (Loss in INR Lakhs)													
East Godavari	2.29	2.74	3.18	4.55	7.97	33.73	Baleshwar	2.25	2.61	2.95	5.54	18.79	169.54
Guntur	0.03	0.03	0.04	0.04	0.05	0.06	Bhadrak	1.65	1.95	4.83	43.56	189.80	640.70
Krishna	-	-	-	-	0.13	3.14	Cuttack						
Prakasam	0.18	0.20	0.22	0.25	0.28	1.42	Ganjam	0.06	0.18	0.23	0.26	0.32	3.47
Sri Potti Sriramulu Nellore	0.25	0.29	1.40	1.67	5.41	32.72	Jagatsinghpur	0.03	0.67	4.24	364.84	925.79	3,009.82
Srikakulam	0.65	1.41	1.47	2.33	2.45	3.44	Jajpur						
Vishakhapatnam	33.56	36.08	38.18	42.96	52.88	74.10	Kendrapara	0.42	1.56	1.79	94.22	383.59	1,136.82
Vizianagaram							Khordha						
West Godavari							Mayurbhanj						
							Puri	0.30	0.34	0.36	0.42	0.48	29.70

District Name	Andhra Pradesh						District Name	Odisha					
Probabilistic Scenarios	**2 Yr RP**	**5 Yr RP**	**10 Yr RP**	**25 Yr RP**	**50 Yr RP**	**100 Yr RP**	**Probabilistic Scenarios**	**2 Yr RP**	**5 Yr RP**	**10 Yr RP**	**25 Yr RP**	**50 Yr RP**	**100 Yr RP**
Industrial (Loss in INR Lakhs)													
East Godavari	50.65	57.20	65.06	79.94	132.61	445.61	Baleshwar	21.97	61.26	163.77	331.17	605.35	2,428.29
Guntur	-	-	-	-	-	5.39	Bhadrak	10.00	10.86	12.13	148.93	1,040.04	3,357.54
Krishna	-	-	-	-	24.62	156.35	Cuttack						
Prakasam	-	-	-	-	3.24	104.64	Ganjam	1,614.49	1,863.20	2,145.12	2,686.03	3,396.71	4,741.33
Sri Potti Sriramulu Nellore	-	-	-	-	-	34.98	Jagatsinghpur	1.14	137.99	361.81	3,858.23	6,577.36	10,555.19
Srikakulam	-	-	-	-	-	-	Jajpur						
Vishakhapatnam	44.85	50.15	52.75	65.44	75.54	172.14	Kendrapara	-	-	-	-	0.26	142.60
Vizianagaram	-	-	-	-	-	-	Khordha						
West Godavari	-	-	-	-	-	-	Mayurbhanj						
							Puri	-	-	-	-	-	64.78

Table 8-2: Distribution of wind losses for different occupancy types by districts

District Name	Andhra Pradesh						District Name	Odisha					
Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP	Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP
Residential (Loss in INR Crores)													
East Godavari	6.22	10.33	15.97	65.43	156.15	344.89	Baleshwar	1.78	5.64	11.03	23.80	41.07	66.98
Guntur	2.88	5.22	12.20	54.89	145.92	333.26	Bhadrak	0.78	2.32	4.90	11.33	20.20	34.15
Krishna	2.65	4.68	11.99	52.59	135.77	309.88	Cuttack	1.36	4.31	11.68	34.34	71.30	132.94
Prakasam	1.74	3.00	4.32	18.96	45.24	102.07	Ganjam	1.17	2.00	7.32	27.48	63.23	133.54
Sri Potti Sriramulu Nellore	3.61	6.31	12.90	54.96	140.91	317.45	Jagatsinghpur	0.80	3.58	9.29	28.12	56.47	106.77
Srikakulam	2.42	4.40	9.70	46.51	122.74	287.57	Jajpur	0.70	2.32	5.33	14.23	27.24	48.99
Vishakhapatnam	7.87	13.81	23.72	103.79	257.49	580.21	Kendrapara	0.18	0.78	1.92	5.40	10.61	19.52
Vizianagaram	0.12	0.21	0.29	1.31	3.11	6.99	Khordha	0.57	1.19	3.14	8.98	18.32	33.98
West Godavari	4.06	6.86	12.75	52.64	130.66	289.24	Mayurbhanj	0.15	0.39	0.74	1.51	2.50	4.00
							Puri	1.34	3.48	9.06	25.53	51.06	94.86
Commercial (Loss in INR Lakhs)													
East Godavari	19.41	32.32	51.54	211.15	506.23	1,120.54	Baleshwar	39.07	120.19	234.80	501.34	863.44	1,406.83
Guntur	14.81	26.83	64.20	289.62	768.52	1,757.62	Bhadrak	40.52	117.84	249.03	572.74	1,021.03	1,730.16
Krishna	14.32	25.22	63.61	277.89	719.44	1,636.52	Cuttack	38.46	123.86	333.51	984.06	2,038.13	3,805.83
Prakasam	12.08	20.89	31.71	138.21	335.56	756.94	Ganjam	20.39	34.79	127.51	477.86	1,102.45	2,328.30
Sri Potti Sriramulu Nellore	16.87	29.53	60.81	260.35	667.81	1,504.99	Jagatsinghpur	31.11	145.52	375.62	1,140.70	2,285.33	4,322.09
Srikakulam	11.72	21.43	47.98	230.83	612.44	1,437.30	Jajpur	25.09	81.72	186.75	495.50	944.23	1,694.66
Vishakhapatnam	24.38	42.65	72.46	316.89	782.06	1,764.02	Kendrapara	29.58	127.69	310.62	864.52	1,693.33	3,095.01
Vizianagaram	0.63	1.07	1.50	6.70	15.87	35.67	Khordha	14.51	28.35	76.81	220.05	451.15	846.48
West Godavari	14.90	25.17	46.81	193.04	478.65	1,059.23	Mayurbhanj	2.84	7.70	14.57	29.64	49.20	78.63
							Puri	29.83	76.58	199.32	559.32	1,118.16	2,074.33
Industrial (Loss in INR Lakhs)													

District Name	Andhra Pradesh						District Name	Odisha					
Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP	Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP
East Godavari	48.00	79.57	119.82	497.83	1,173.13	2,569.52	Baleshwar	48.42	155.78	308.73	665.41	1,144.69	1,872.84
Guntur	29.94	54.23	112.62	510.75	1,339.27	3,059.60	Bhadrak	30.13	91.04	190.45	442.22	782.92	1,313.73
Krishna	32.35	56.69	135.58	590.18	1,529.91	3,467.74	Cuttack	29.96	86.45	238.71	688.96	1,457.01	2,698.31
Prakasam	25.92	44.34	62.61	269.23	653.73	1,461.68	Ganjam	38.53	75.05	270.94	1,020.17	2,414.44	5,039.09
Sri Potti Sriramulu Nellore	29.23	51.64	118.74	523.19	1,348.91	3,056.48	Jagatsinghpur	23.80	126.21	323.66	978.49	1,921.77	3,660.99
Srikakulam	14.68	25.43	41.50	184.07	454.90	1,034.25	Jajpur	1.66	5.66	13.85	40.76	82.18	152.88
Vishakhapatnam	31.52	54.85	96.09	413.33	1,031.13	2,289.89	Kendrapara	20.96	95.18	235.51	671.18	1,328.60	2,436.57
Vizianagaram	4.90	8.34	12.19	52.62	127.36	285.16	Khordha	6.82	12.31	31.78	84.74	168.19	307.45
West Godavari	35.53	59.75	107.01	444.17	1,085.70	2,409.21	Mayurbhanj	2.56	6.92	13.01	26.55	43.74	69.10
							Puri	31.87	74.95	201.04	566.64	1,149.97	2,168.66

Table 8-3: Distribution of flood losses for different occupancy types by districts

District Name	Andhra Pradesh						District Name	Odisha					
Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP	Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP
Residential (Loss in INR Lakhs)													
East Godavari	327.58	2,482.58	1,995.59	1,411.97	3,762.54	6,252.89	Baleshwar	456.74	1,204.70	1,680.32	2,419.46	2,172.25	2,699.98
Guntur	272.74	1,530.87	1,108.62	1,771.91	2,656.10	4,096.93	Bhadrak	723.31	1,110.14	1,347.72	1,693.77	1,558.91	1,854.75
Krishna	100.40	1,036.25	870.02	1,246.63	1,474.71	1,638.48	Cuttack	1,710.66	2,470.64	3,005.27	4,425.10	3,782.67	4,943.08
Prakasam	246.99	842.43	519.17	622.21	710.18	761.93	Ganjam	141.95	207.63	224.90	266.71	249.80	280.43
Sri Potti Sriramulu Nellore	650.93	2,140.19	1,176.74	1,302.41	1,374.11	1,579.24	Jagatsinghpur	1,315.26	3,015.52	3,823.75	5,766.33	5,013.29	6,533.81
Srikakulam	3,984.37	10,445.51	5,242.32	8,043.10	9,232.65	10,558.14	Jajpur	946.10	1,336.05	1,552.31	2,024.46	1,833.88	2,172.92
Vishakhapatnam	392.15	1,070.09	595.24	683.95	720.13	776.17	Kendrapara	584.10	926.32	1,144.60	1,545.50	1,372.52	1,715.24

District Name	Andhra Pradesh						District Name	Odisha					
Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP	Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP
Vizianagaram	10.28	39.65	22.27	25.50	27.66	30.12	Khordha	96.03	156.19	191.46	278.76	234.79	313.72
West Godavari	2.00	5.27	13.98	3.81	56.81	199.27	Mayurbhanj	20.11	25.42	27.49	39.49	31.27	41.40
							Puri	65.16	350.09	562.07	1,006.42	831.70	1,181.58
Commercial (Loss in INR Lakhs)													
East Godavari	11.64	47.23	79.09	53.40	148.86	239.49	Baleshwar	57.22	181.87	272.99	349.67	390.41	429.93
Guntur	9.01	35.48	53.63	108.89	163.27	223.63	Bhadrak	184.52	289.13	355.53	410.63	450.82	504.60
Krishna	7.24	19.81	25.19	42.72	50.07	62.18	Cuttack	421.37	637.26	791.72	999.70	1,186.34	1,324.17
Prakasam	11.09	19.45	24.44	29.38	38.93	45.89	Ganjam	16.80	29.91	31.99	37.66	41.81	45.39
Sri Potti Sriramulu Nellore	16.05	24.23	35.31	39.99	44.41	48.75	Jagatsinghpur	306.90	707.61	913.52	1,224.69	1,430.58	1,645.29
Srikakulam	166.54	205.35	264.06	294.27	329.45	363.86	Jajpur	249.04	356.15	408.86	484.53	533.85	572.31
Vishakhapatnam	146.69	167.63	133.80	194.07	161.07	174.90	Kendrapara	586.38	912.65	1,148.53	1,390.35	1,596.43	1,774.19
Vizianagaram	-	-	-	-	-	-	Khordha	13.90	21.05	25.73	30.26	35.65	42.60
West Godavari	0.84	0.89	0.89	0.89	1.87	8.97	Mayurbhanj	0.44	0.60	0.69	0.99	1.71	2.45
							Puri	11.81	54.80	83.50	113.12	133.62	152.49
Industrial (Loss in INR Lakhs)													
East Godavari	50.11	521.93	902.55	602.60	1,348.33	1,924.80	Baleshwar	308.88	808.10	1,076.46	1,376.54	1,535.10	1,645.84
Guntur	-	6.67	18.78	56.75	91.01	157.88	Bhadrak	366.41	715.39	903.47	1,092.15	1,211.48	1,355.86
Krishna	1.62	110.31	134.07	226.75	255.31	303.71	Cuttack	406.24	596.31	705.80	863.75	941.27	1,034.59
Prakasam	73.04	100.74	111.03	156.91	179.02	195.28	Ganjam	226.99	876.28	893.08	1,023.92	1,055.62	1,059.75
Sri Potti Sriramulu Nellore	80.44	121.60	131.34	173.22	184.33	200.29	Jagatsinghpur	694.24	4,800.01	5,579.68	6,649.93	7,148.16	7,705.57
Srikakulam	399.76	530.50	601.62	645.23	698.58	746.28	Jajpur	38.96	42.54	45.74	56.55	59.84	64.88
Vishakhapatnam	189.25	224.98	252.42	301.72	323.79	343.70	Kendrapara	2,082.66	3,054.85	3,568.76	4,117.20	4,471.59	5,134.11

District Name	Andhra Pradesh						District Name	Odisha					
Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP	Probabilistic Scenarios	2 Yr RP	5 Yr RP	10 Yr RP	25 Yr RP	50 Yr RP	100 Yr RP
Vizianagaram	-	-	-	-	-	-	Khordha	4.73	8.79	9.89	11.25	11.61	18.28
West Godavari	0.53	0.59	0.59	0.59	15.94	49.41	Mayurbhanj	2.66	8.98	11.17	12.58	13.15	14.09
							Puri	23.82	121.47	200.99	238.52	269.77	302.17

END OF REPORT