GRIDCO
Empowering Odisha

CDRI
Coalition for Disaster Resilient Infrastructure

Strategies for Effective Risk Identification and Estimation

Component II, Task I

Disaster Resilient Power Systems for Odisha

Power Research and
Development Consultants
Private Limited

KPMG Advisory Services
Private Limited

TARU Leading Edge
Private Limited

Foreword

Power infrastructure and a stable electricity connection is an essential enabler of development. It supports homes, businesses, schools, hospitals, and the supply of other utilities. The introduction of smart grid technologies, bolstering renewable energy sources, and enhancing load efficiency is imperative for achieving global climate commitments.

Escalating climate risks present a challenge to this essential infrastructure and its interconnected systems. Power infrastructure in coastal regions is particularly vulnerable given the magnitude of climate intensified extreme weather events in these regions.

India has a coastline stretching over 7,500 kilometres. Its coastal areas are home to more than 260 million inhabitants. Cyclones like Fani (2019), Gaja (2018), and Hudhud (2014), which were accompanied by severe flooding, caused extensive damage to lives and livelihoods across the coastal states of Odisha, Andhra Pradesh, Tamil Nadu, and Kerala.

In response, India has become a leader in building resilience in coastal areas. Improved disaster preparedness, early warning systems, and well-executed evacuation strategies, have played a pivotal role in safeguarding vulnerable populations.

Odisha's experiences in recovering quickly from various disaster events offer compelling evidence for the development of resilient power infrastructure. The state became the first state in India to establish a disaster management authority in 1999 after the Super Cyclone, even before the establishment of the National Disaster Management Authority (NDMA) in 2005. It was also the first Indian state to create an early warning system for disseminating critical disaster-related information to the very last mile. Odisha State Disaster Management Authority has utilized the best technical expertise for building over 800 multi-purpose cyclone shelters together with evacuation roads along the state's entire coastline. Odisha's success in bringing down the casualty to double digits and putting in place robust mechanisms for risk-informed decision-making is a significant achievement.

In support of these efforts, recognizing the particular importance of power infrastructure, and to develop evidence that can be shared with other vulnerable regions, CDRI's study "Disaster Resilient Power Systems for Odisha" has aimed at strengthening the power infrastructure.

This work has identified key challenges and best practices within the Transmission and Distribution (T&D) sector at the subnational level. To understand vulnerabilities related to the T&D infrastructure system along its entire 480 km of coastline, 16 indicators were identified ranging from commissioning year to asset failure history. Recommended actions, including investment options to strengthen resilience of the T&D infrastructure, were prepared accordingly. The study serves as a vital resource for stakeholders in the power sector.

On behalf of CDRI, I express sincere gratitude to all stakeholders from the Government of Odisha, including GRIDCO Ltd, for their invaluable contributions to the report's methodology and policy recommendations for the short, medium, and long term. I would also like to extend my sincere appreciation for NDMA's support throughout the entire effort. Collaboration with Taru Leading Edge, Power Research and Development Consultants (PRDC), and KPMG - India has been instrumental in preparing this report, which serves as an indispensable tool for policymakers, practitioners, manufacturers, and other stakeholders in the power sector.

CDRI believes that the resilience of the power sector to extreme weather events is pivotal in safeguarding the lives and livelihoods of millions, particularly those in vulnerable regions. We are committed to take the lessons learned in Odisha and expand similar work to support coastal regions around the world.

Amit Prothi
Director General, CDRI
New Delhi, India, June 2024

Foreword

Global energy consumption is steadily increasing annually, with an anticipated 48 percent growth over the next two decades, driven by the exponential rise in global population. In the face of escalating challenges posed by climate change, ensuring resilience in energy systems is imperative for overall development. Given the historical impact of extreme weather events on the state of Odisha, particularly the Transmission and Distribution (T&D) segment, the state has demonstrated remarkable resilience. It has rebounded and recovered by developing innovative adaptation and mitigation strategies in response to periodically changing wind speeds and the looming risk of climate change.

Understanding the socio-economic impact and losses in this regard, this study serves as an essential tool and a precursor at the sub-national, national, and global levels for coastal regions and regions with similar geographies. It provides insights into strategies that can be replicated not only for risk identification and estimation but also for capacity building, knowledge management, and financial preparedness.

This initiative aims to evaluate the climate resilience of Odisha's power infrastructure in a unique way. It will not only help in reshaping the policy landscape and risk-based governance for coastal regions but also provide valuable insights for energy sector practitioners, Original Equipment Manufacturers (OEMs), and regulators. The report details individual unit-level assets, their vulnerabilities, and offers investment options on how to build more resilient transmission and distribution assets. By setting a new standard for resilience initiatives, the study is expected to significantly influence the development of robust and adaptive energy systems, ensuring a sustainable and secure future for all.

I extend my appreciation to the Coalition for Disaster Resilient Infrastructure (CDRI) and the project stakeholders for this collaborative effort, which will help enhance the reliability and resilience of the state's power infrastructure. I strongly believe that the report will serve as a benchmark in climate-proofing of energy infrastructure in Odisha.

Principal Secretary to Government
Energy Department,
Government of Odisha

Preface

India is highly vulnerable to various natural hazards such as cyclones, tsunamis, earthquakes and floods, among other catastrophes. Approximately 12 percent of the nation's land area is prone to flooding and river erosion, while more than 58 percent is vulnerable to earthquakes of moderate to very high intensity (MHA, 2015). The susceptibility to cyclones and tsunamis affects approximately 76 percent of the coastline, particularly impacting the eastern coastal states of Tamil Nadu, Andhra Pradesh, Odisha and West Bengal (CEA, 2021). Climate change has increased the frequency and severity of these catastrophic events, wreaking havoc on the economy and society.

Odisha, with a 480-km coastline along the Bay of Bengal, often faces severe impacts from these disasters. Power infrastructure is one of the most severely affected sectors in the region. Large-scale damage to the state's transmission and distribution (T&D) infrastructure due to cyclones is common, leading to extended power supply outages in affected areas. Additionally, floods in Odisha are another major obstacle to the electricity infrastructure, making it impossible to operate and maintain during high rains and severe waterlogging. Between 1996 and 2018, Odisha experienced 13 years of floods and five years of cyclones (Sethi, 2019).

In light of the profound consequences that climate change and disasters have on power infrastructure, the National Disaster Management Authority (NDMA) of India convened a meeting in July 2019, inviting all stakeholders involved in developing policy and research at the national level, as well as those involved in building and operating power generation, transmission and distribution infrastructure in Odisha. The meeting discussed the power sector's damages and losses and brainstormed a road map for creating disaster- and climate-resilient power infrastructure in Odisha and, by extension, in all high-risk areas of India. The meeting also involved a thorough analysis of the cyclone's impact on the power infrastructure in Odisha, including the technical, organizational and functional factors contributing to significant damage and prolonged power restoration, which was universally acknowledged.

The following action was proposed to move forward: NDMA, in cooperation with relevant stakeholders, would conduct a comprehensive study to improve the power sector's disaster and climate resilience. Drawing from Odisha's experience, the power sector has adopted various innovative approaches to mitigate the effects of cyclones. These innovations, which have been adopted on an on-going basis over the last two decades, need to be systematically documented and disseminated so that the advances made by Odisha may benefit other cyclone-affected states in the country. The Coalition for Disaster Resilient Infrastructure (CDRI) supports NDMA in carrying out this comprehensive assessment of the resilience of power infrastructure in Odisha state.

The study on the resilience of power infrastructure in Odisha is categorized into two distinct phases. Phase I of the study relates to developing and adopting mechanisms for ensuring preparedness, preventing grid collapse, assessing losses, estimating needs and channelling adequate funds to disaster-affected areas promptly for early restoration and resilient recovery and reconstruction. It also includes aspects of community engagement.

The Phase - II study consists of two components, which yield a total of five reports. Component II focus areas include a) Risk Identification and Estimation and b) Codes, Standards, Regulations, Technology and Innovation. Component III focuses on a) Risk-based Governance and Policy Development, b) Capacity Building and Knowledge Management and c) Financial Preparedness and Adaptation.

The Phase-II reports will be a crucial instrument for policymakers to strengthen the power system's resilience, particularly in terms of T&D assets. Additionally, they will aid in evaluating and ranking investments in the power sector among similar geographical areas at every level.

The report **'Strategies for Effective Risk Identification and Estimation'** aims to differentiate the level of susceptibility and the associated risks faced by Odisha's power infrastructure due to disasters. Evaluation has meticulously considered exposure and vulnerabilities, particularly within the various components of the power infrastructure.

The report **'Codes, Standards and Technological Innovations for Infrastructure Design'**, an examines various mechanisms crucial for establishing, enforcing, and regularly updating scientifically informed design standard, codes, and regulations to enhance power infrastructure resilience. This assessment factored in evolving technologies and their changing profiles to ensure efficacy. This study also considers an array of technologies and innovations available to bolster power structure resilience against diverse hazards, emphasizing the tools and technologies that could be integrated to strengthen disaster risk management.

The report **'Risk-Informed Governance and Policy Development'** reflects the need to imbibe strong institutional governance, augmented capacity building and financing for disaster resilience in the power sector. The report further recommends and provides a way forward to build a comprehensive post-disaster need assessment (PDNA) strategy and enhance the techno-regulatory capacity building of Odisha's power infrastructure. It additionally identifies the various gaps and provides plausible interventions to strengthen the resilience in both structural and non-structural aspects of the power sector in the state.

The report **'Capacity Building of Stakeholders for Better Preparedness'** addresses governance and policy structures coupled with capacity-building efforts and makes recommendations for different stakeholders of the state and Energy department. These recommendations aim to facilitate the integration of disaster and climate resilience principles into the planning, operation, maintenance and continuous improvement of power infrastructure in Odisha.

The report **'Financial Preparedness Strategies for Adaptation and Resilience'** states that financial resources are required at various stages to build further disaster-resilient infrastructure, such as disaster prevention, preparedness, response and recovery. This section of the report addresses the financial and adoption strategies.

Acknowledgements

The successful completion of the Disaster Resilient Power Systems study for coastal Odisha stands as a testament to the extensive collaborative and technical effort invested over three years.

The project encompassed thorough desk research, data collection, cleaning, analysis and calculations. The successful accomplishment of this monumental task would not have been possible without the unwavering dedication and hard work of numerous individuals and teams, to whom we express our sincere appreciation and gratitude.

We would like to express our gratitude to Shri Gagan Bihari Swain, Director (F&CA), GRIDCO and his team for their valuable guidance and coordination in collecting relevant data from different stakeholders during the study period. We also appreciate the contributions of OPTCL, TPCODL, TPNODL, TPSODL and OSDMA in providing the required information for the study.

We extend our heartfelt appreciation to our esteemed consultants, M/s Power Research and Development Consultants Private Limited-PRDC, M/s KPMG India and M/s Taru Leading Edge, for their critical contributions to the study.

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Abbreviations

ADB	The Asian Development Bank
AIS	Air-Insulated Substations
DEM	Digital Elevation Model
DISCOM	Distribution Company
DP	Double Pole
DSS	Distribution Substations
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Gas Insulated Substation
GRIDCO	Grid Corporation of Odisha Limited
GSS	Grid Substation
HVA	Hazard Vulnerability Assessment
IDF	Intensity - Duration - Frequency
IMD	India Meteorological Department
IoT	Internet of Things
NDMA	National Disaster Management Authority
OSDMA	Orissa State Disaster Management Authority
OPTCL	Odisha Power Transmission Corporation Limited
PSS	Primary Substation
RCP	Representative Concentration Pathway
S/S	Substation
SLD	Single Line Diagram
2D	Two Dimensional
T&D	Transmission and Distribution
TPCODL	Tata Power Central Odisha Distribution Limited
TPNODL	Tata Power Northern Odisha Distribution Limited
TPSODL	Tata Power Southern Odisha Distribution Limited
TPWODL	Tata Power Western Odisha Distribution Limited
UNDRR	United Nations Office for Disaster Risk Reduction
VI	Vulnerability Index

Executive Summary

In the last three decades, the escalating severity of extreme weather events such as droughts, heat waves, heavy rains and cyclonic storms has highlighted the dire consequences of global climate change. These events have caused considerable damage to infrastructures, with cyclonic winds displaying a particularly alarming increase in both frequency and intensity.This heightened ferocity has led to extensive damage to T&D (transmission and distribution) systems, especially in coastal regions. Coastal states like Odisha have withstood the worst of these amplified cyclonic forces, underscoring the pressing need for disaster and climate-resilient power infrastructure. This situation presents a compelling opportunity to emphasize the critical imperative of rebuilding and reinforcing these vital energy systems. It is now more crucial than ever to focus on fortifying the T&D infrastructure in Odisha and across the nation to ensure greater resilience in these increasingly severe weather events.

Component-II report Task-1: 'Strategies for Effective Risk Identification and Estimation' endeavours to draw a clear distinction between the degree of vulnerability and the associated risks posed to Odisha's power infrastructure in the wake of hazards, focusing on cyclones and flooding.This comprehensive assessment encompasses the preparation of hazard zonation maps and meticulously evaluates asset exposure levels, vulnerability degrees and potential risks. Lines and substations categorized with varying priorities require prompt attention to verify their capacity to withstand wind speeds in accordance with established standards and codes.

The report prioritizes critical power infrastructure assets and identifies gaps in the availability of data and information essential to enhance the resilience of the power sector. There commendations arising from this study promise to significantly enhance the disaster resilience of power infrastructure within the country. Moreover, these insights can serve as a valuable blueprint for similar geographical regions, contributing to the protection and fortification of T&D infrastructure in the face of ever-changing global climatic patterns.The report analyses the assets of the distribution companies in Odisha, namely Tata Power Central Odisha Distribution Limited (TPCODL), Tata Power Northern Odisha Distribution Limited (TPNODL), Tata Power Southern Odisha Distribution Limited (TPSODL) and the transmission company Odisha Power Transmission Corporation Limited (OPTCL).

Tropical cyclones cause considerable damage to structures and result in loss of life in coastal areas of Odisha. In this context, cyclone micro-zonation is a step forward in identifying assets at cyclone risk. Micro-zonation helps in site-specific hazard analysis, providing input for infrastructure design and land use management. It classifies larger regions into microzones with varying wind speeds. The report highlights cyclone zonation for different return periods (5,10, 25, 50,100) by considering the gust speed map with a 50-year return period for analysis. The hazard zonation map, representing a 50-year return period, indicates that 10 percent of coastal locations in the state receive wind speeds above 60 metre per second (m/s). Such high wind speeds can cause substantial damage to both physical assets and individuals. The maps demonstrate that districts like Puri, Jagatsinghpur, Kendrapada and Ganjam are vulnerable to violent storms.

The flood maps were created by running a two-dimensional (2D) hydrodynamic model, specifically focusing on pluvial flooding. According to the maps, flooding is particularly severe in districts like Jagatsinghpur, Kendrapada, Bhadrak, Balasore, Puri and Ganjam. The model ran the current scenario with varying return periods of 5, 25, 50 and 100 years. The results showed that water depths reached 1.13 m in several places.

Asset Exposure

The assessment of asset exposure is essential to comprehensively gauge the vulnerability of T&D infrastructure to disaster- and climate-related risks. The asset class in the report encompasses distribution substations, distribution lines, transmission grid substations and transmission lines to provide a comprehensive understanding of the associated risks.

The cyclone exposure maps clearly indicate that both the T&D and distribution assets are extremely vulnerable to severe storms, especially in districts such as Puri, Jagatsinghpur, Kendrapada and Ganjam. The 50-year return period exposure map suggests that about 10 percent of coastal locations in the state receive wind speeds above 60 m/s. These high wind speeds significantly impact coastal areas up to 0-60 km from the coastline, particularly on T&D assets.

When overlaying power infrastructure onto flood hazard maps, it becomes evident that the transmission system is least impacted, whereas the distribution infrastructure is considerably affected. Some districts have approximately 30 percent of DISCOM's infrastructure exposed to flooding in a 100-year return period scenario. The analysis of flood exposure to the power infrastructure for a 5-year return period indicates that approximately 5.6 percent of the infrastructures in TPCODL are at risk. TPCODL has 6.2 percent and 6.5 percent of its power infrastructure in danger of flooding for a 100-year return period in the current and future scenarios. The TPNODL has a greater proportion of vulnerable infrastructure in comparison to other DISCOMs. The Kendrapada district is the most vulnerable district covered by TPCODL, while the Bhadrak district is the most vulnerable district covered by TPNODL. TPSODL assets are not exposed to flood hazards.

Vulnerability and Risk Assessment

Vulnerability is a function of the degree of exposure, sensitivity and adaptive capacity. Not all exposed infrastructures are equally vulnerable, i.e., certain infrastructures may have relatively better adaptive capacity to cope with the impact of cyclones or flood hazards. A hazard vulnerability assessment (HVA) methodically assesses the potential damage that could result from a disaster. The severity of vulnerability aids in pre-disaster planning and resource allocation. To evaluate vulnerability, a list of physical indicators was examined for transmission substations, lines, distribution lines and substations. Sixteen appropriate indicators were chosen, and each of these indicators was assigned a score on a scale ranging from 1 to 4. While high scores indicate greater vulnerability, a composite score was calculated by assigning equal weightage. Vulnerability was then categorized as low, medium, or high based on the composite score.

Over 30 percent of vulnerable distribution substations are located within 20 km of the seacoast. The impact is exacerbated by ageing infrastructure, as nearly 75 percent of distribution lines were commissioned three decades ago. Vulnerability primarily arises from the suboptimal design of the supports for these distribution lines. Approximately 80 percent of the poles are of the joist or PSC designs, making them susceptible to high wind speeds. Additionally, longer span lengths, specifically 70 m or more, are observed in 80 percent of the 33 kV lines, which increases their susceptibility to damage.

More than half of the relatively highly vulnerable transmission substations are found within 0 to 20 km of the shoreline, indicating their exposure to potentially high wind speeds with varying degrees of vulnerability. In addition to this, air-insulated substations (AIS) are the most common in coastal areas, comprising 54 percent, and 19 percent of these have reported a history of failures, which further increases their vulnerability. In contrast to distribution lines, three-quarters of the transmission lines are operating within their expected service life. Around nine percent of highly vulnerable transmission lines are found within 20 km of the shoreline.

Criticality and Prioritization

Critical power lines serve essential establishments such as water supply, telecommunication services, healthcare facilities, transportation, rescue operations and district administrative buildings. During cyclones or floods, the loss of power to these vital services can have a severe impact on rescue operations. Therefore, it is important to identify these critical power lines and the corresponding substations that supply electricity to these essential services. Certain components in the power infrastructure are extremely susceptible to risks, which could then have a major influence on the whole system's connectivity. These assets are also regarded as critical. The study aims to identify critical power lines, substation and associated components that are exposed to multiple hazards. Based on vulnerability and criticality assessments, these lines and substations will be prioritized for retrofitting or modification of their components to enhance their resilience against multiple hazard risks.

Four priority options, ranked from 1 to 4 based on the order of intervention, have been identified for all the mapped assets. Priority 1 indicates a greater need to strengthen the power infrastructures, whereas Priority 4 implies that no strengthening is necessary. According to the prioritization, there are a total of 71 33 kV lines designated to the Priority 1 category in TPNODL, 52 in TPCODL and 34 in TPSODL. In the instance of PSS (primary substation), Priority 1 includes 18 PSS in TPCODL, 5 in TPNODL and 2 in TPSODL. For 11 kV lines, the first priority should be 146 TPSODL lines, 144 TPNODL lines and 138 TPCODL lines. OPTCL, on the other hand, has fewer lines and grid substations (GSS) in Priority 1, with most of them being under Priority 4. Priority 1 has one 220 kV line and three 132 kV lines but no 400 kV lines. Priority 4 has 11 400 kV, 83 220 kV and 228 132 kV lines. Priority 1 has four 220 kV GSS and seven 132 kV GSS.

Recommendations

It is essential to systematically collect and store damage information, including images, in a digital geographic information system format within the central repository. This is because the data regarding infrastructure damage caused by past disasters such as cyclones and floods is currently incomplete, scattered, or not systematically compiled. Having spatially informed data on damaged assets can facilitate innovative design solutions and enhance preparedness for future events.Furthermore, it is recommended that, for future disaster assessments, a systematic spatial evaluation be conducted in accordance with the post-disaster need assessment frameworks outlined by the Global Fund for Disaster Risk Reduction (GFDRR). In Odisha, there is an available spatial inventory of power transmission network assets, and distribution companies are in the planning or on-going phases of creating digital asset inventories for distribution assets. With such forward-looking initiatives, the spatial database should also be continually updated to include routine repairs of assets and record information about newly added assets. In addition, regular annual audits of the data inventory should be implemented.

1 Introduction

1 Introduction

Climate change has caused considerable damage to infrastructure systems, resulting in massive economic and societal losses. The power sector infrastructure has been particularly hard hit by various disasters, and its heterogeneous nature renders it even more susceptible to damage (World Bank, 2019). Consequently, decisions regarding the building of system resilience will be based upon a comprehensive evaluation of the prevailing perils in the area, as well as the susceptibilities and exposure of diverse power infrastructure elements,particularly the transmission and distribution assets to those perils. It is necessary to disseminate this information at the proper dimensions so that it can guide decisions regarding climate resilience and disaster preparedness.

From 1999 to 2021, the impact of cyclones on Odisha's power infrastructure amounted to over INR 98 million, accounting for around 25 percent of the total losses incurred. Cyclone Fani in Odisha resulted in significant destruction to the power infrastructure, underscoring the inadequacy of the current assessments of the anticipated intensity of cyclonic winds (i.e. hazard intensity). Therefore, there is an urgent need to improve the resilience of Odisha's power infrastructure by conducting a comprehensive risk assessment of its components. This evaluation will enable the formulation of the most effective recommendation for investment prioritization.

This report, titled 'Strategies for Effective Risk Identification and Estimation' aims to distinguish between the levels of vulnerability and associated risks to Odisha's power infrastructure by disasters, specifically focusing on cyclones and flooding. The report seeks to understand the existing power infrastructure setting in Odisha through a literature review and stakeholder consultations during on-site visits. Hazard zonation maps have been developed by considering the likelihood of their occurrences under future scenarios. To identify the exposed assets, the state's power infrastructure assets have been mapped and overlaid onto the resulting hazard zonation maps. Critical components and vulnerabilities of these assets have been identified based on their level of importance. A prioritization of assets has been conducted based on their vulnerability, criticality and exposure to determine the order of importance for making investments. The report concludes with a list of recommendations to improve the resilience of the power infrastructure to climate and disasters.

2 Baseline Diagnosis

2 Baseline Diagnosis

Prior to devising any interventions or investigations, it is crucial to conduct a baseline/landscape analysis to fully comprehend the current state, ongoing activities and potential outcomes in the absence of any interventions. The ensuing sections present a comprehensive outline of the various risks present in Odisha, along with an assessment of their impact on the power infrastructure.

2.1 Cyclone Hazard

Since 1970, the coastal region of India has been struck by 274 cyclones, making them the most common threat in the area (World Bank, 2013). The 1999 Super Cyclone that struck Odisha was among the most powerful cyclones ever documented in the previous century (Kalsi, 2006). The cyclone was responsible for the death of nearly 10,000 persons. It prompted a paradigm shift in the disaster management capacities of the state. Following the Super Cyclone, Odisha was the first state in India to institute a disaster management authority. In fact, the organization, now known as the Odisha State Disaster Management Authority (OSDMA), was established prior to the National Disaster Management Authority (NDMA) being established in the country in 2005 (Jena & Kouamé, 2023). Odisha is now considered a leader in cyclone preparedness and management in the entire country.

Odisha has been hit by several significant cyclones over the last decade (Cyclone Phailin in 2013, Cyclone Hudhud in 2014, Cyclone Titli in 2018, Cyclone Fani in 2019, Cyclone Bulbul in 2019, Cyclone Amphan in 2020 and Cyclone Yass in 2021). The frequency of cyclones has increased significantly over the past decade, affecting an increasing number of power facilities and their dependant sectors that rely on them, including water, telecommunications, sewerage and health. It is crucial to understand and quantify the risks and impact of these cyclones for proper asset planning and management.

When calculating the risk associated with each degree of influence, it is beneficial to consider first-order risks, second-order risks and third-order risks. First-order risks directly influence the operations of the entity (in this case, the power sector). Second-order risks are that have an indirect impact on the sector and third-order risks are those that have an impact on other sectors and should be carefully examined in detail. The subsequent section discusses first-order risks associated with major cyclones in Odisha, with particular emphasis on Cyclone Fani. Due to limited information from primary and secondary sources, only Cyclone Fani has been explored in relation to second- and third-order risks.

2.1.1 First-Order Risk

In this context, the first-order risk relates to cyclone-induced direct asset loss in the power sector. As seen in Table 2.1, six major cyclones in the state alone have inflicted INR 97,864.3 million in damage to the power infrastructure, accounting for almost 25 percent of the total damages caused by all six cyclones.

This estimate includes damage to both distribution and transmission lines. Cyclone Fani in 2019 caused the most damage, inflicting INR 81,390 million worth of damage on the power sector (Chatterjee & Shaw, 2020). According to the Memorandums of various cyclone hazards, Odisha Government SRC (Special Relief Commissioner) (1999-2021), the majority of the damages were observed in the 11 kV and 33 kV lines, low-tension lines, 220 kV and 130 kV towers, feeders and distribution substations.

Table 2.1 Economic loss to Odisha power sector by cyclones

Year	Name of Cyclone	Districts Affected	Peak Wind Speed (km/h)	Total Damage (INR, million)	Damage to Power Sector (INR, million)	% of Total Damage to Power Sector
1999	Super Cyclone	14	260-70	62,275.90	4000.00	6.42
2013	Phailin	19	214	42,424.10	10,481.40	24.71
2014	Hudhud	11	80-100	7,790.00	600.00	7.70
2018	Titli	17	130-40	27,793.20	1,330.30	4.79
2019	Fani	9	205	241,760.00	81,390.00	33.67
2019	Bulbul	9	110	2,244.20	62.60	2.79
Total				**384,287.40**	**97,864.30**	**25.47**

Source: Chatterjee & Shaw, 2020

2.1.1.1 Cyclone Fani

Cyclone Fani made landfall on the Odisha coast on 3 May 2019, bringing a sustained surface wind speed of 205 km/h. The impact of the cyclone resulted in the loss of 64 lives and affected 16.5 million individuals in 14 of the 30 state districts. Among these districts, Puri, Khordha, Cuttack, Jagatsinghpur and Kendrapada suffered the most severe damage. Furthermore, the cyclone caused prolonged power outages in several regions of the state, impacting an estimated 4.7 million people (ADB, 2019).

The power sector incurred significant damage, amounting to INR 81,390 million (Chatterjee & Shaw, 2020). Following an evaluation in 2019-20 by The Asian Development Bank (ADB) with the cooperation of the Odisha government, the damages to electricity infrastructure included 400 kV, 220 kV, 130 kV towers and 200 high-tension poles, as well as 11,077 distribution transformers and 79,485 km of low-tension lines. Figure 2.1 shows some of the damages incurred by the power infrastructure due to Cyclone Fani.

Figure 2.1: Damages to the power infrastructure during Fani Cyclone (SRC-2019)

2.1.2 Second-Order Risk

This section provides an overview of the indirect impact of cyclones on the power sector. This is associated with the Odisha state's financial losses in relation to power infrastructure, which can be categorized into two groups: revenue losses incurred by DISCOMs due to power supply disruptions and income losses suffered by metre readers and bill collectors (as these tasks are outsourced to third parties by DISCOMs). According to the ADB's 2019 estimate, DISCOMs lost INR 2500 million in revenue, while meter readers/bill collectors suffered losses amounting to INR 35 million, resulting in a total loss of INR 2535 million (ADB, 2019).

2.1.3 Third-Order Risk

Third-order risk refers to the influence of power sector damage on other sectors, such as public health, education and banking. In 2019, the Odisha government released a memorandum detailing the extensive impact and damages caused by the extremely severe cyclonic storm 'FANI' across various sectors. Some of the affected areas experienced disruptions, including banking services, which were unavailable due to power and internet outages. Consequently, regular business operations in banks were disrupted, and power outages also impacted piped water systems, leading to water shortages in four districts, including in the state capital of Bhubaneshwar. To address these potential emergencies, a power backup arrangement was made for 242 public health institutions (SRC, Odisha, 2019).

2.2 Flood Hazard

Floods in Odisha mainly occur in the Mahanadi, Brahmani and Baitarani rivers due to their shared delta. The Jagatsinghpur region of Odisha has been identified as a severe flood-prone region, experiencing inundation as floodwaters from these rivers overflow and merge, submerging the surrounding areas. The impact of flooding is exacerbated by the influx of water from the neighbouring states of Jharkhand and Chhattisgarh.

The coastal regions exhibit a flat topography characterized by minimal slope, poor drainage, soil erosion and significant siltation in river basins and delta areas. The issue is exacerbated when high tides align with floods. In addition, the entire coastal area is extremely susceptible to storm surges, which puts the shore at risk of both seasonal and cyclonic floods that pose serious threats to human life, livestock, houses, crops and infrastructure. The low-lying substations are at risk of flooding following a cyclone (Chatterjee & Shaw, 2020).

Floods substantially impact indirect losses, which are frequently not quantified. Indirect consequences include the deterioration of farmland, leading to a reduction in agricultural output and affecting rural development and income prospects. This is particularly important in the coastal region of Odisha, where there is a significant reliance on agricultural produce to sustain livelihoods.

2.3 Other Hazards

Other hazards that Odisha faces, besides flooding and cyclones, are lightning and kalbaisakhi (a localized rainfall and thunderstorm event). In recent years, lightning and kalbaisakhi have been growing.

From 2011 to 2020, lightning strikes resulted in a total of 3218 fatalities. According to the 2020-2021 Annual Lightning Report, Odisha remains the state with the highest number of lightning strikes (IMD, 2021). The Mayurbhanj district has witnessed the most lightning-related fatalities, followed by the Keonjhar and Ganjam districts.

Kalbaisakhi is characterized by sudden and intense thunderstorms accompanied by powerful gusts, heavy rainfall, lightning and occasionally hail. These storms often occur in the afternoon or evening and can be highly severe, damaging property, crops and infrastructure within the impacted regions.

2.4 Onsite Observations

The consultant team visited Puri, Berhampur and Paradeep to retrieve records, gather data and gain insights from the experiences of line personnel and front-line staff at substations. The purpose of the site visit at Pandiabil – Samagara Line, near Puri, on 17 August 2021, was to document the effects of Cyclone Fani on the poles and lines that were damaged.The visit was conducted together with discussions with officials from the DISCOMs. Cyclone Fani had damaged a total of 66 220 kV towers. Towers numbered 77 to 166 of the Pandiabil - Samagara 220 kV DC line were observed to have sustained damage and were later dismantled following the cyclone. The towers in question had been commissioned in 2015. The majority of the poles that sustained damage were Joist Poles. The Paradeep Substation (33/11 kV substation) had experienced multiple damages during previous cyclones and floods, such as bending, uprooting and breaking of poles caused by falling trees. Rahama, Tirtola, Kujanga and Eresama are four circles that had experienced significant impacts from previous cyclones and flooding. One of the contributing factors to the uprooting of poles and towers was the soil strata. Figure 2.2 presents some of the photos captured during the site visit to the Paradeep substation. The next site visit was conducted at the Gopalpur area, located near Berhampur, on 18 and 19 August 2021. The region had suffered significant devastation due to the cyclone, resulting in damage to 5000 11 kV poles, 4000 low-tension poles and 250 33 kV poles. The records show that the power outage impacted a total population of around 0.1 million. According to local authorities, the damaged power lines were restored within 45 days. Figure 2.3 shows the damage to the power infrastructure seen during the field visit to Gopalpur.

Figure 2.2: Site visit to Paradeep substation (33/11 kV substation)

Figure 2.3: Site visit to Gopalpur substation

3 Methodology

3 Methodology

The process of identifying and mapping risks related to different hazards is divided into five sections, as illustrated in Figure 3.1. First, the hazard assessment involves creating cyclone and flood zonation maps, with the results presented in Sections 3.1 and 3.2. Section 3.3 assesses the exposure of power infrastructure assets to these hazards. Furthermore, Section 3.4 provides vulnerability and risk assessment of various infrastructures through an indicator-based method. The next phase entails evaluating the susceptibility and risk of different infrastructures and thereby assessing the infrastructure that is more susceptible and crucial, which is further elaborated in Section 3.5. This section also outlines the process for prioritizing assets for climate-proofing.

Figure 3.1: Methodology of risk identification, mapping and estimation

Section 3.1-3.2	Hazard Zonation and Mapping	Cyclone Micro zonation	Cyclone hazard Map	Fig. 3.2 Annexure 1
		Flood Hazard Modelling	Flood hazard Map	Fig. 3.5, 3.6 Annexure 2
Section 3.3	Exposure Assessment	Transmission and distributions substations and lines: Assests exposed	Cyclone Exposure List	Fig. 3.7, 3.8 Annexure 1
			Flood Exposure List	Table 3.1
Section 3.4	Vulnerability Analysis	Cyclone Vulnerability	Vulnerable Asset list	Table 3.3 - 3.14 Annexure 3
		Flood Vulnerability		
		Multi-Hazard Vulnerability		
Section 3.5	Criticality Assessment	Importance Based	Critical Assets List	Fig. 3.11 - 3.13 Table 3.15, 3.16
		Risk Based		
	Priority Assessment	Priority Matrix	Prioritization asset list	Table 3.18-3.20

3.1 Cyclone Zonation Maping

Cyclone micro-zonation is a systematic approach used to identifying assets susceptible to cyclone hazards. A micro-zonation system divides a larger area into micro-zones characterized by distinct wind velocities. Micro-zones aid in site-specific hazard evaluations, providing valuable information for designing infrastructure and managing land use.

To conduct micro-zonation, the first step would be to map the available historical paths of cyclones in the region. Subsequently, the study area was divided into grids. The grid resolution is variable, with finer grids generated for coastal areas and coarser grids for locations further inland to ensure that less significant cyclones do not overshadow the impact of significant cyclones. Additionally, it was assumed that the centre of the grid (site) coincided with the centre of the circle of influence. The circle of influence has a radius of 200 km and was drawn around each grid point. Cyclone track points were established along the cyclone eye, where the maximum wind speed occurs, based on the documented locations of cyclone eyes as specified in the cyclone track information.

The tracks of cyclones as they make landfall in each influential region are extracted. Following that, the wind speeds of the cyclone are calculated at each grid point by utilizing the wind field model developed Goyal & Datta (2012). The cumulative distribution function (CDF) of wind speeds at the site is determined using Weibull's probability distribution method. As described by Goyal and Datta in 2012, the annual recurrence probability calculation is performed using Poisson's distribution. The probability of 'n' cyclone occurring in time 't' is expressed as

$$P(n,t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$$

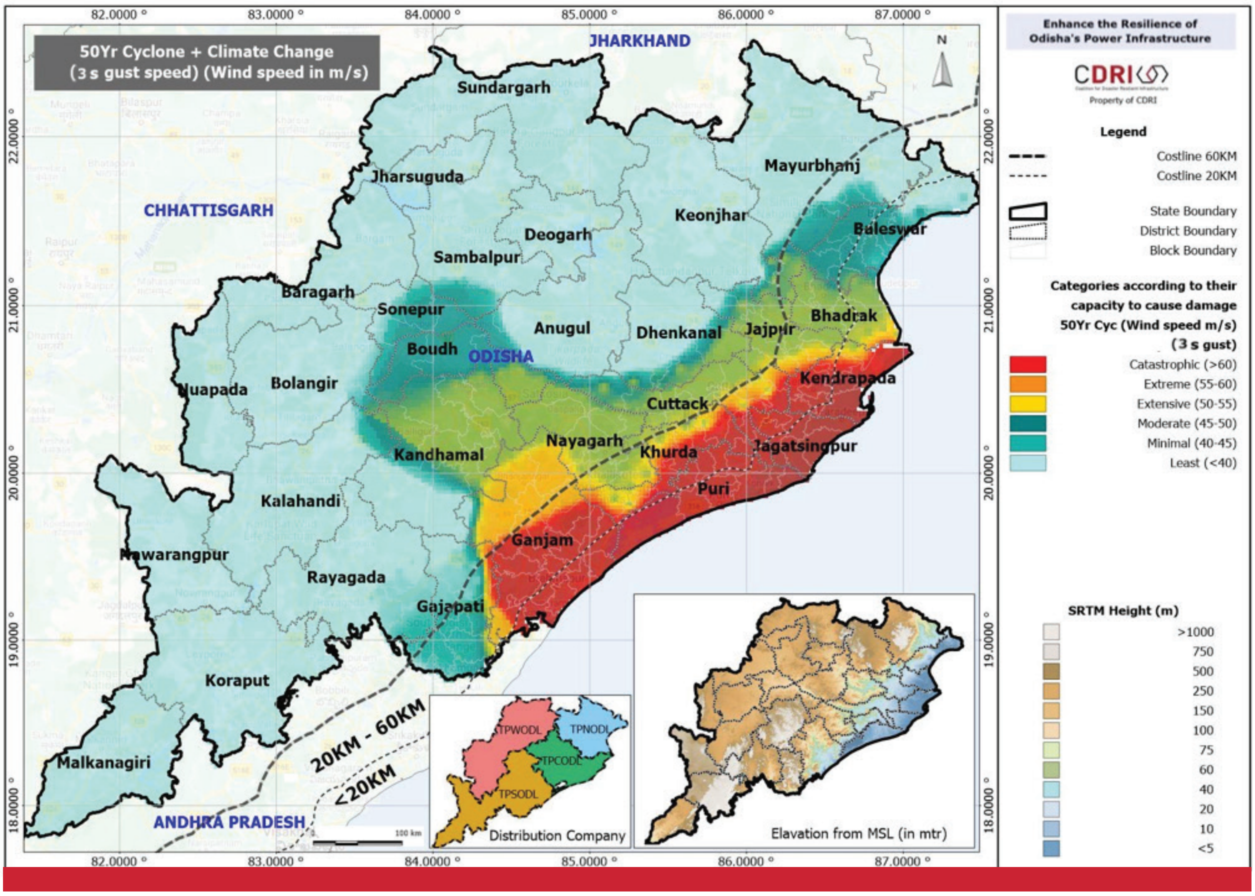
'λ' is the average tropical cyclone occurrence rate per year.

The computation of exceedance probability for various return durations is performed for each individual grid point. The return periods of 100 years (V100), 50 years (V50), 25 years (V25), 10 years (V10) and five years (V5) are calculated for vulnerability assessments. The different ratios, including V50/V100, V25/V50, V25/V10, V10/V5, were computed for every grid point. Plots of histograms were created for each of these ratios, revealing significant differences between the values at the tail and the mean values. Hence, the mean ratios obtained were employed to estimate these revised wind speeds to get a more accurate assessment of the different speeds (V50, V25, V10, V5).

To integrate climate change into the analysis, two distinct climatic scenarios for cyclones on the East Coast of India, as suggested by Rao (2019), have been selected. These scenarios are categorized as extreme and moderate climate change scenarios. The extreme climate change scenario considers an 11 percent increase in wind speed, while the moderate climate change scenario considers a 7 percent rise in wind speed.

The Central Electricity Authority (CEA) recommends utilizing the 3-second gust speed for cyclone zoning and developing electrical infrastructure networks (CEA, 2021). According to the CEA authority, the impact of cyclones decreases as they move from the sea to the land area. In accordance with CEA recommendations, the maximum sustained wind speed zonation map generated by the aforementioned approach is converted into a 3-s gust speed zonation map. Typically, the damage to infrastructure is confined to approximately 60 km from the coastline. The first 20 km experiences the most significant impacts and necessitates the implementation of stronger infrastructure systems (CEA, 2021).Hence, during the preparation of the cyclone zonation map, the consultant team has considered buffer zones of 0-20 km, 20-60 km and beyond 60 km from the shore. This is to gain a more comprehensive picture of the infrastructure that is at risk. The cyclone zonation map for a 3-second gust speed with a 50-year return period (Figure 3.2) clearly indicates that districts such as Ganjam, Puri, Khordha, Jagatsinghpur and Kendrapada see wind speeds above 60 m/s, making them very susceptible to extreme events. The map displaying the maximum sustained wind speeds for different return durations can be found in Annexure 1.

Figure 3.2 :Cyclone Zonation Map - (Gust Speed - 50 year Return Period)

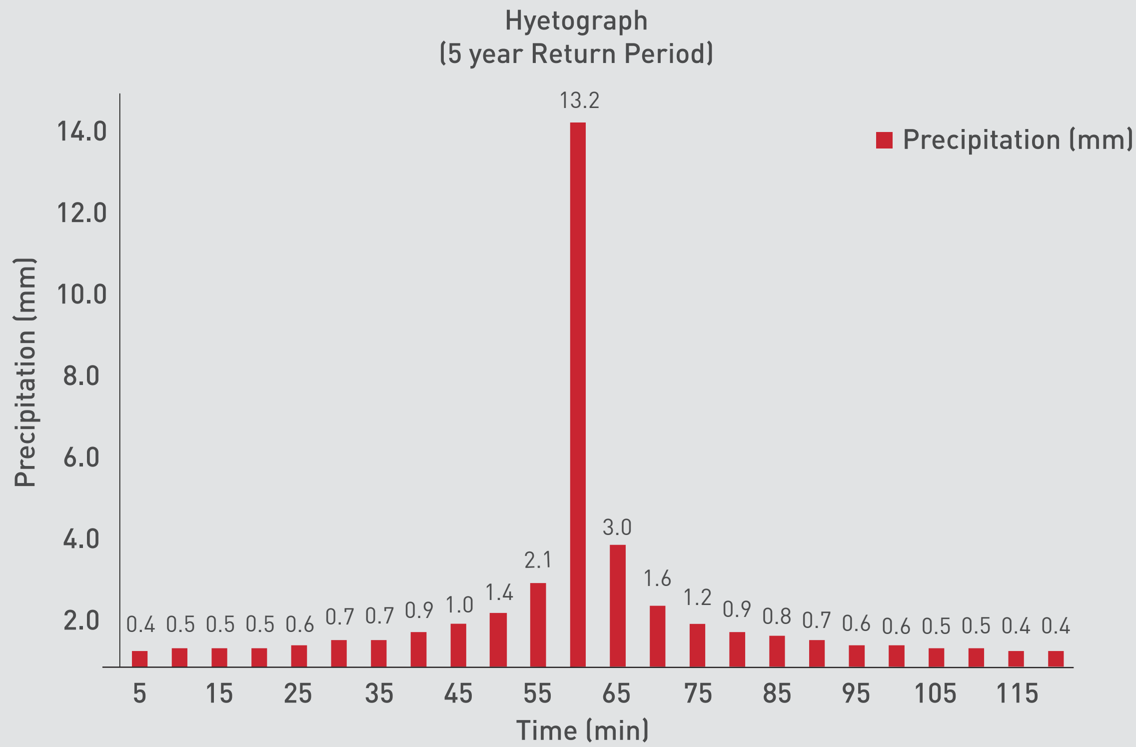


3.2 Flood Zonation Mapping

Surface water flooding, pluvial flooding, flash flooding, cloudburst and storm runoff are all interchangeable terms used to denote the occurrence of flooding following a heavy downpour. These happen when rain falls to the ground faster than it can be absorbed or discharged, leading to water accumulation and the potential for properties to be inundated. Surface water flood occurrences often have localized effects, affecting properties in close proximity to where the rain fell and for a brief period. This is the type of flooding considered in the analysis; however, another type of flooding known as fluvial flooding, which occurs when water from rivers and streams breaks their banks and flows out onto adjacent low-lying areas, has not been considered in detail due to a lack of data (please refer to section 5 for more information).

The first step in determining pluvial flooding in a region involves conducting a rainfall frequency analysis. The methodology for this analysis is outlined in CPHEEO (2019). India Meteorological Department's (IMD) daily gridded rainfall data for coastal districts was analyzed, and Intensity - Duration - Frequency (IDF) curves and rainfall hyetographs (Figures 3.3 and 3.4) were generated.The estimated rainfall was applied to investigate pluvial flooding in flood-prone districts of Odisha, including Jagatsinghpur, Kendrapada, Bhadrak, Balasore, Puri and Ganjam. HEC-RAS software was used in the two-dimensional (2D) modelling of the districts' catchments to estimate the pluvial flood caused by short, strong rainfall. The SRTM 30 m digital elevation model (DEM) was utilized, with a constant manning's value of 0.035 across the whole model domain. The 2D model domain has been purposefully extended beyond the actual area of the district to depict potential flooding scenarios within the districts accurately. The current scenario was considered with different return periods, specifically 5, 25, 50 and 100 years.

River floods have a significant influence in districts such as Jagatsinghpur and Kendrapada. Consequently, the consultant team specifically included certain averaged river flow from publications, as well as different return period hyetographs for these districts. However, river flow was not considered for the pluvial flood study in other coastal areas such as Bhadrak and Balasore. The consultant team had previously collected DEM data for the Puri city area, which proved helpful when performing detailed pluvial flood analyses in the region. Figure 3.3 displays the hyetographs relating to the IDF curves for return periods of 5, 25, 50 and 100. The hyetographs exhibit a bell-shaped pattern, with the intensity increasing as the return period increases. For example, the peak rainfall for a return period of 5 years is 13 mm/min, while for a return period of 100 years it is 16 mm/min.Figure 3.4 illustrates the IDF curves, which depict the rainfall intensity (in mm/h) and duration (in minutes) for different return periods. The maximum rainfall intensity is around 200 mm/h for a scenario with a return period of 100 years. The hyetographs generated for the coastal districts of Odisha show minimal variations when analyzed over multiple return periods. As a result, flood maps with a return period of 100 years have been used for the assessment


Hyetograph
(5 year Return Period)
Precipitation (mm)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
13.2
3.0
2.1
1.6
1.4
1.2
0.4 0.5 0.5 0.5 0.6 0.7 0.7 0.9 1.0
0.9 0.8 0.7 0.6 0.6 0.5 0.5 0.4 0.4
5 15 25 35 45 55 65 75 85 95 105 115
Time (min)

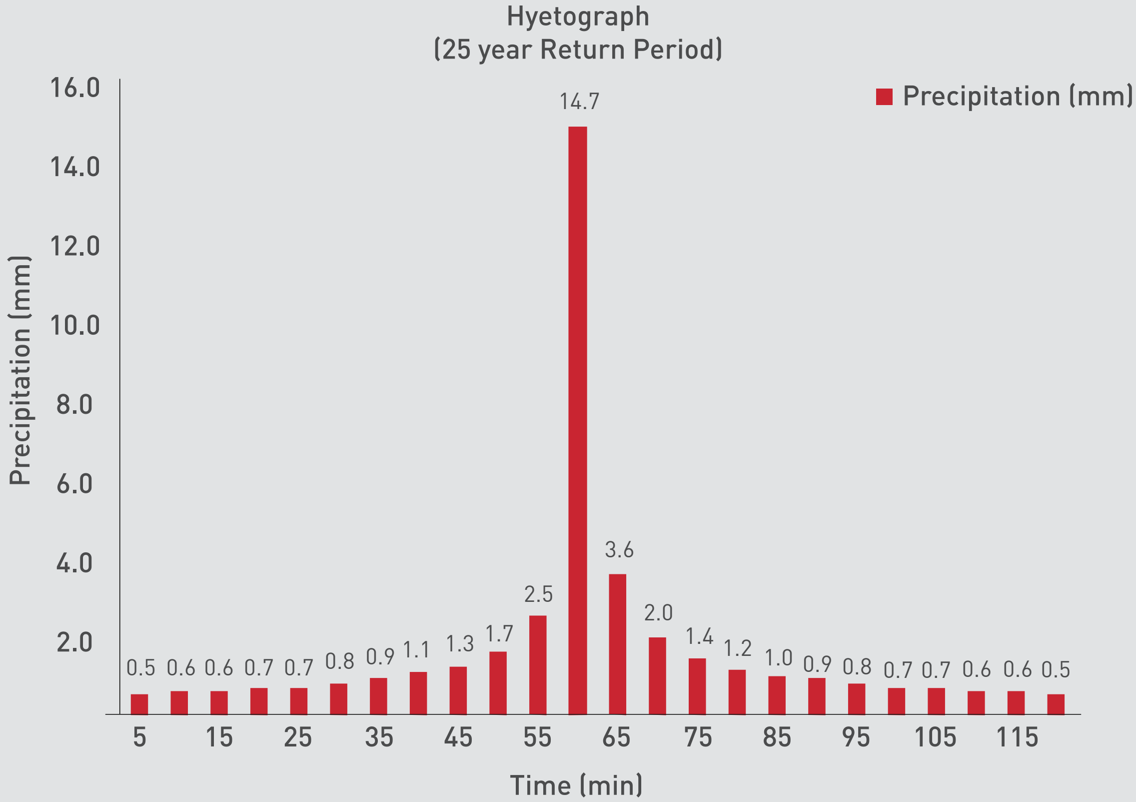

Hyetograph
(25 year Return Period)
Precipitation (mm)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
14.7
3.6
2.5
2.0
1.7
1.4
1.3
1.2
1.1
1.0
0.5 0.6 0.6 0.7 0.7 0.8 0.9
0.9 0.8 0.7 0.7 0.6 0.6 0.5
5 15 25 35 45 55 65 75 85 95 105 115
Time (min)

Figure 3.3: Hyetograph with 5-, 25-, 50- and 100-year return period

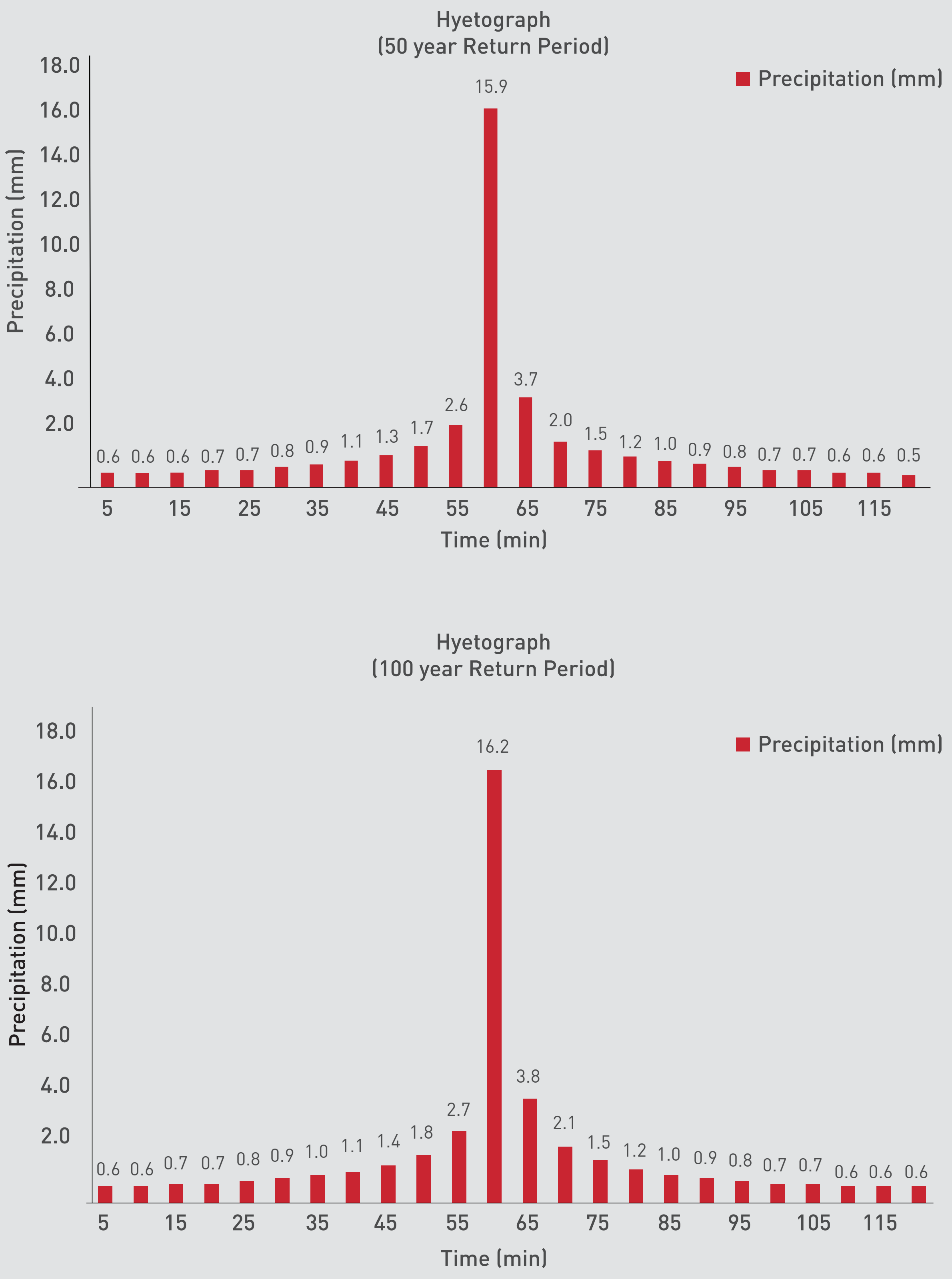
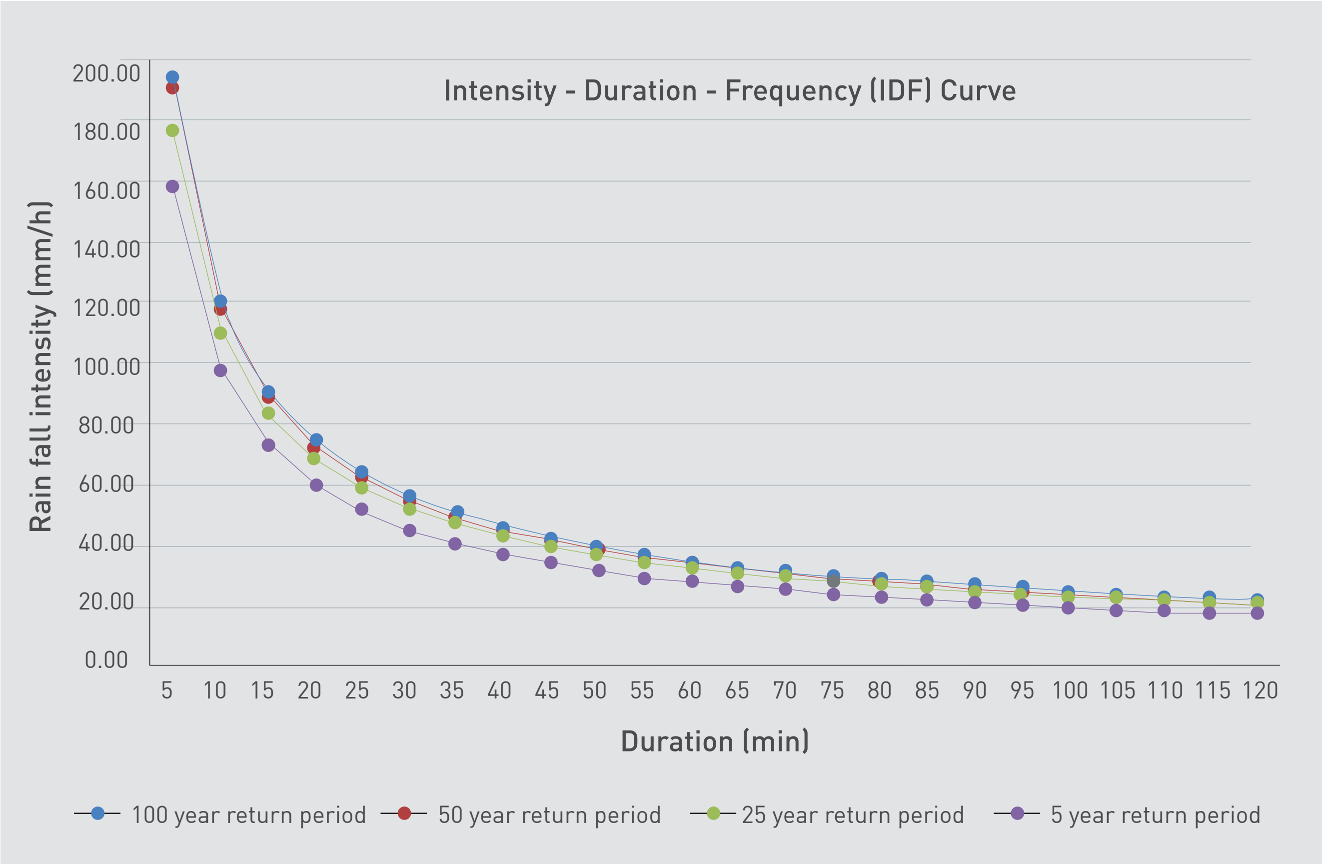


Figure 3.4: IDF curve for 5-, 25-, 50-, and 100-year return period



Flood zonation map was created for the region using the established approach. In Figures 3.5 and 3.6, an example of the flood zonation map for the Kendrapada district, depicting the 1 in 5-year and 1 in 100-year return periods, can be observed. Annexure 2 displays the flood zoning maps for Balasore, Bhadrak and Jagatsinghpur, including the 5-, 25-, 50- and 100-year return period maps. For future scenarios (next 30 years), downscaled ensemble mean from various climate models such as BNU-ESM (Beijing Normal University Earth System Model), CanESM (Canadian Earth System Model), CNRM-ESM (Centre National de Recherches Météorologiques Earth System Model), MPI-ESM-LR (Max Planck Institute Earth System Model - Low Resolution) and MPI-ESM-HR (Max Planck Institute Earth System Model – High Resolution) for both RCP (representative concentration pathway)-4.5 and RCP-8.5 was used. An estimation of different return period hydrographs using the daily projected rainfall and simulated pluvial flood models was carried out to understand flash flooding and water logging. The resultant future scenario maps for the 5- and 100-year return periods are given in Annexure 2.

Figure 3.5: Flood zonation map-1 in 5 years return period (Kendrapada district)

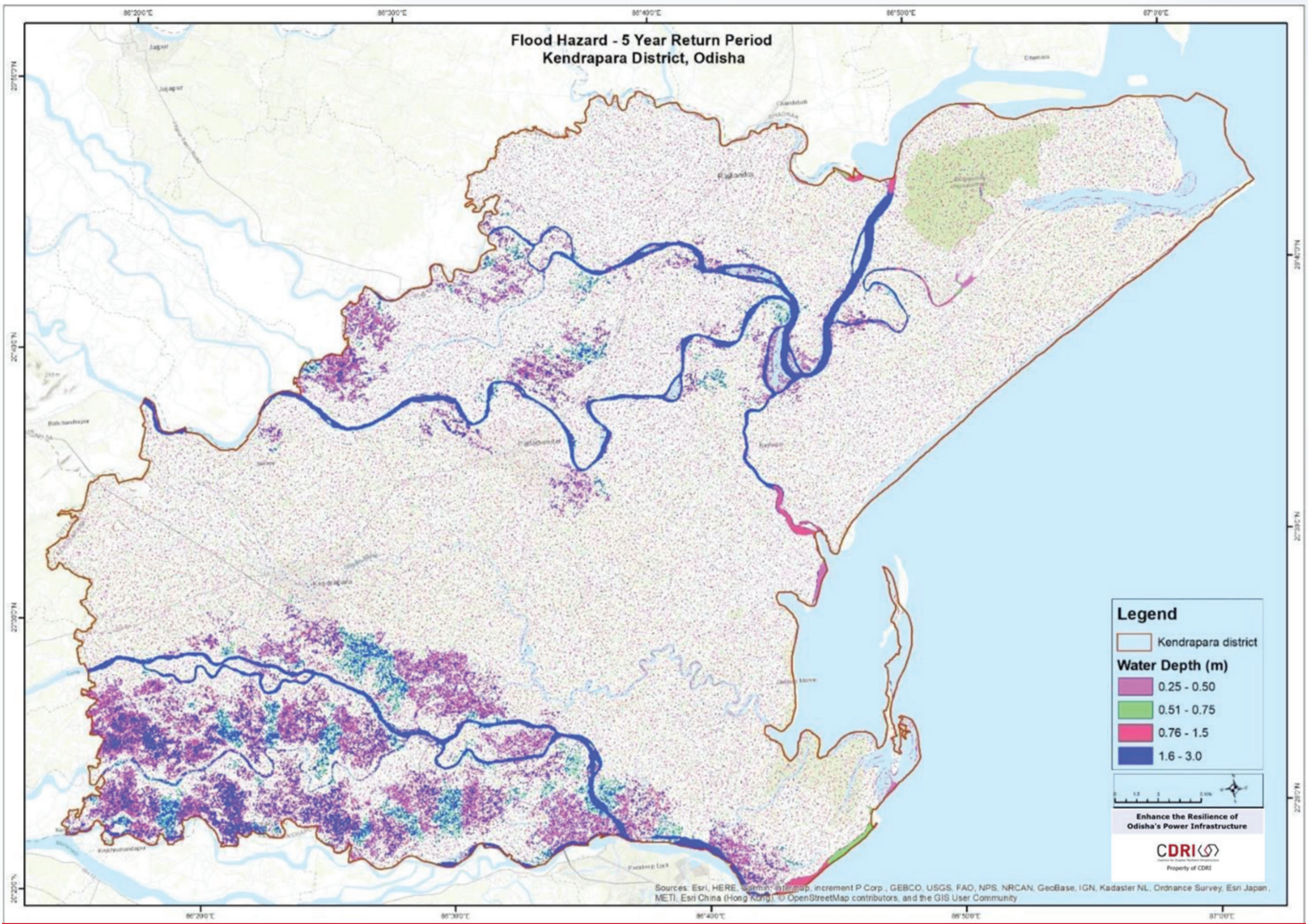
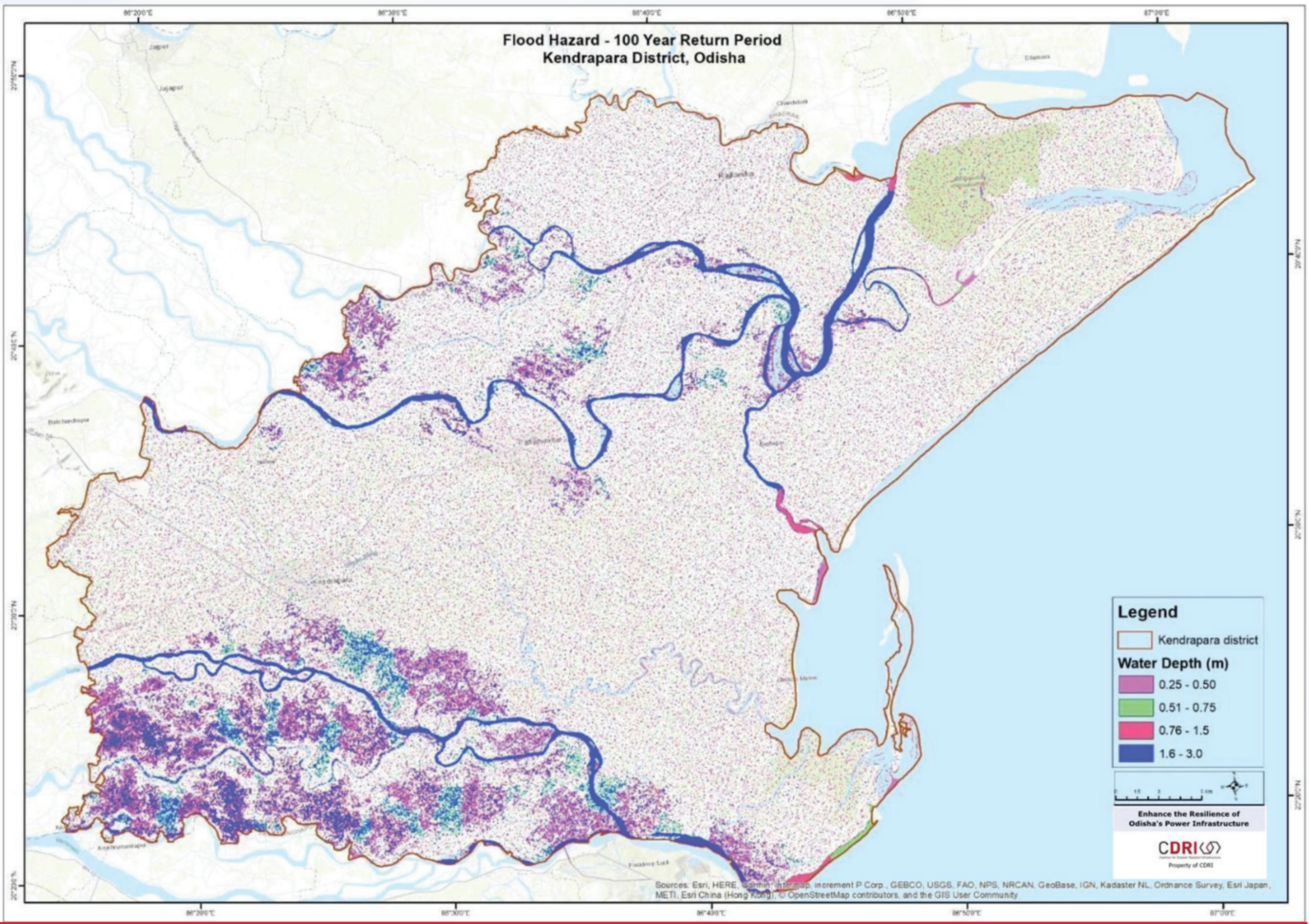


Figure 3.6: Flood zonation map-1 in 100 years return period (Kendrapada district)



3.3. Exposure Assessment

The term 'exposure' refers to the presence of people, livelihoods, species or ecosystems, infrastructure, environmental functions, services, resources, or assets related to the economy, society, or culture in locations and situations where adverse effects could occur (IPCC, 2022). This study evaluates vulnerability to two major hazards: cyclones and floods. The exposure assessment entails overlaying previously developed hazard zonation maps onto power infrastructure components and determining the elements most susceptible to these risks.

3.3.1 Cyclone Exposure

The power infrastructure in the coastal districts of states is at risk due to the intense and frequent wind speeds of cyclones. These recurrent episodes of intense cyclones impose significant social and economic costs and challenge the resilience of infrastructure to its utmost capacity. According to the hazard zonation map, representing a 50-year return period, indicates coastal areas in odisha experience wind speeds exceeding 60m/s causing substantial damage to both physical assets and people. The transmission and distribution (T&D) power networks in these areas would be substantially impacted compared to areas experiencing wind speeds below 50 m/s.

Figures 3.7and 3.8 represent exposed assets resulting from a cyclone in a 50-year return period:

1) Transmission network exposure

2) T&D substation exposure

The maps clearly indicate that the T&D assets are extremely vulnerable to severe storms, especially in areas such as Puri, Jagatsinghpur, Kendrapada and Ganjam. Annexure 1 provides supplementary maps showing the exposure in relation to a 100-year return period, taking climate change into consideration.

Figure 3.7: Transmission line exposure to 1 in 50-year return period

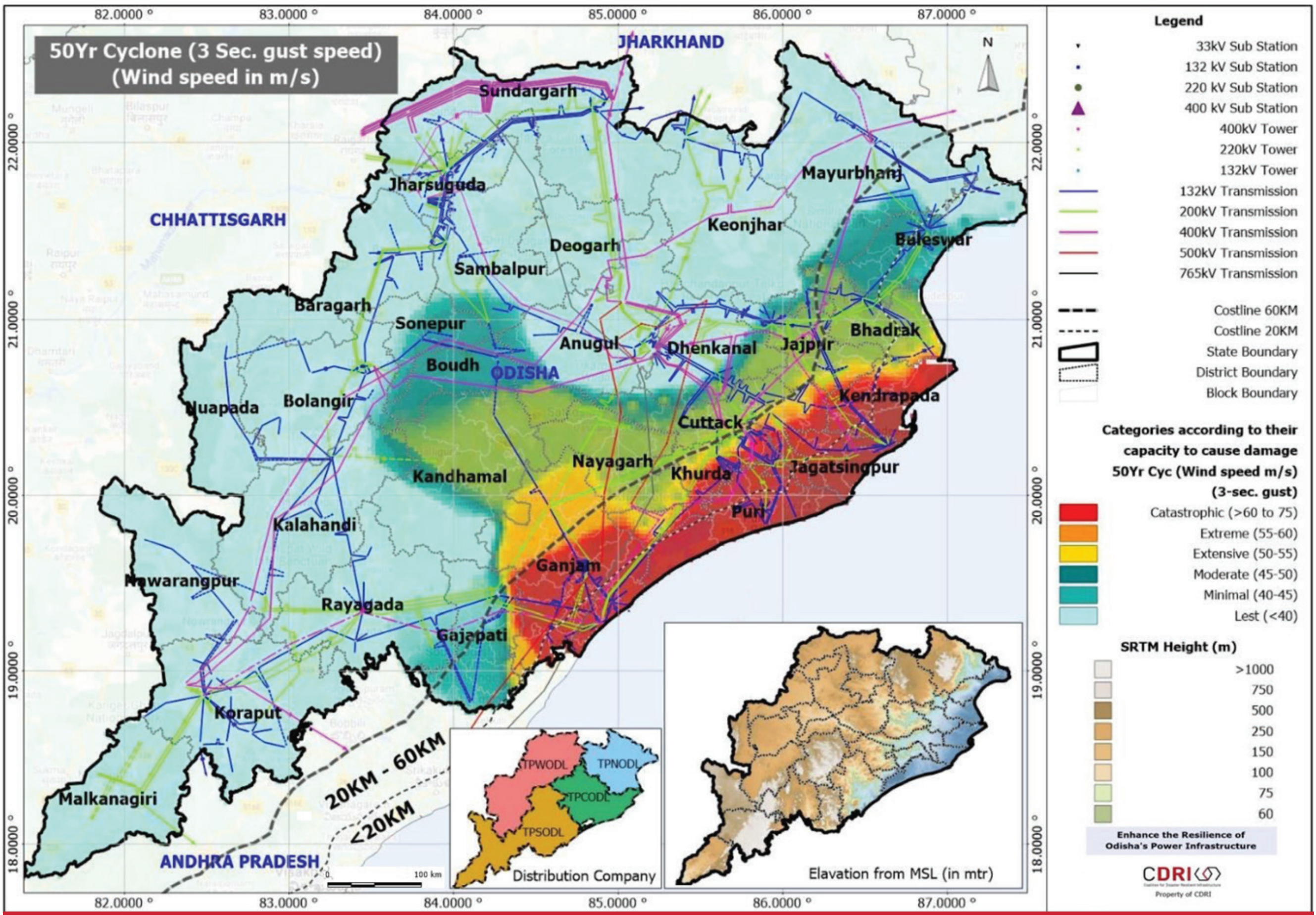
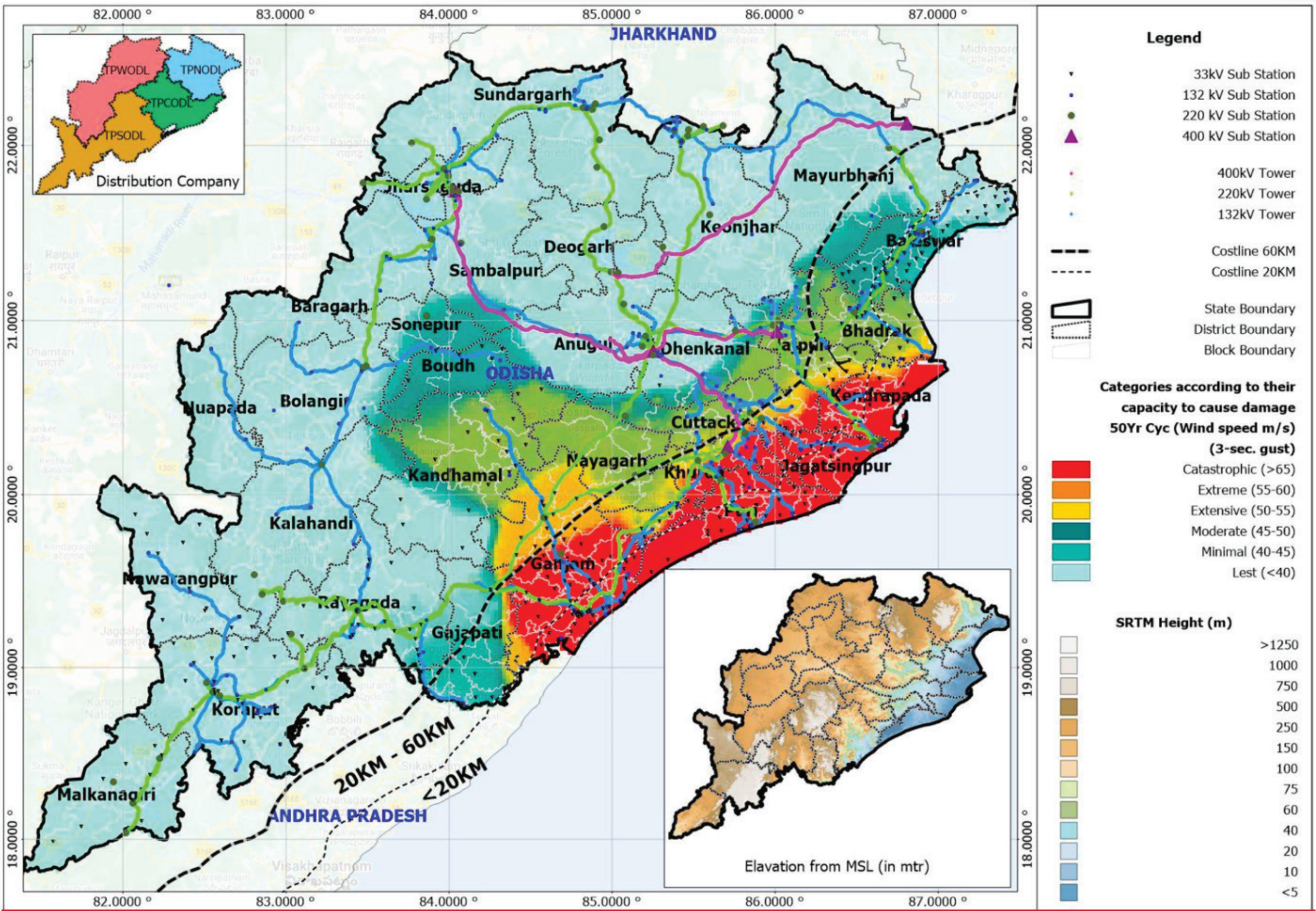


Figure 3.8: Transmission and distribution substations exposure to 1 in 50-year return period



3.3.2 Flood Exposure

Overlaying power infrastructure onto flood maps shows that, as anticipated, the transmission system is least impacted, whereas the distribution infrastructure is significantly affected. In a 100-year return period scenario, some districts have approximately 25 percent of their infrastructure exposed to flooding. Table 3.1 presents the percentage of flood exposure to different DISCOMs across different return periods.

Table 3.1: Percentage of power infrastructure exposed to floods in different return periods

DISCOM/Districts	Flood Exposure w.r.t. Power Infrastructure		
	1 in 5 (Current Scenario) Year Return Period	1 in 100 (Current Scenario) Year Return Period	1 in 100 (Far Future) Year Return Period
TPCODL	5.6%	6.2%	6.5%
Angul	0.0%	0.0%	0.0%
Cuttack	4.8%	4.8%	4.8%
Dhenkanal	0.0%	0.0%	0.0%
Jagatsinghpur	15.0%	20.0%	20.0%
Kendrapada	25.0%	28.1%	31.3%
Khordha	0.0%	0.0%	0.0%
Nayagarh	0.0%	0.0%	0.0%
Puri	12.5%	12.5%	12.5%
TPNODL	11.1%	11.9%	13.3%
Balasore	19.7%	21.3%	24.6%
Bhadrak	24.2%	27.3%	30.3%
Jajpur	5.3%	5.3%	5.3%
Keonjhar	0.0%	0.0%	0.0%
Mayurbhanj	5.8%	5.8%	5.8%
TPSODL	0.0%	0.0%	0.0%
Gajapati	0.0%	0.0%	0.0%
Ganjam	0.0%	0.0%	0.0%

The analysis of flood exposure to the power infrastructure for a 5-year return period indicates that approximately 5.6 percent of Tata Power Central Odisha Distribution Limited (TPCODL) infrastructures are at risk. The average depth of the flood here ranges from 0.01 m to 0.80 m. Under present and future scenarios, TPCODL has 6.2 percent and 6.5 percent of its power infrastructure in danger of flooding for a 100-year return period. The Tata Power Northern Odisha Distribution Limited (TPNODL) has a higher proportion of vulnerable infrastructure than other DISCOMs. Around 11.1 percent of assets are at risk of being affected by floods in a 5-year return period scenario, with water depths ranging from 0.01 m to 1.13 m. In addition, the current scenario reveals that 11.9 percent of assets are at risk of floods occurring in a 100-year return period scenario, while in the future scenario, this risk increases to 13.3 percent. The Kendrapada district emerges as the most vulnerable district covered by TPCODL, whereas the Bhadrak district holds this status under TPNODL. It was found that Tata Power Southern Odisha Distribution Limited (TPSODL) assets are not exposed to flood hazards.

3.4. Vulnerability Assessment

Infrastructure vulnerability refers to the system's sensitivity or susceptibility to harm and its lack of capacity to cope and/or adapt to stresses and shocks (CDRI, 2023). It is one of the defining components of disaster risk (UNDRR, 2017). Evaluating the vulnerability based on the associated risk level is crucial to determining the losses suffered and the financial resources needed. In assessing infrastructure vulnerability to natural hazards such as cyclones and floods, it is important to note that not all exposed infrastructures are equally vulnerable. Certain infrastructures may possess better adaptive capabilities to withstand the effects of cyclones or floods. A set of physical indicators related to transmission substations and lines, as well as distribution substations and lines, were evaluated to evaluate the susceptibility of the power infrastructure. Sixteen appropriate indicators were chosen based on their correlation with infrastructure vulnerability. They were each assigned a vulnerability score on a scale ranging from 1 (indicating low vulnerability) to 4 (indicating high vulnerability). Table 3.2 comprehensively explains the indicators, including their characteristics and ratings. Subsequently, the assets are categorized as having low, medium, or high vulnerability.

Table 3.2: Indicators, parameters and score for vulnerability assessment

	No.	Indicators	Parameters	Score	Remarks
Distribution Primary Sub Station (PSS)	1.	Year of Commissioning	▪ Less than 30 years ▪ More than 30 years	1 4	Infrastructures outlived their services life are more at risk.

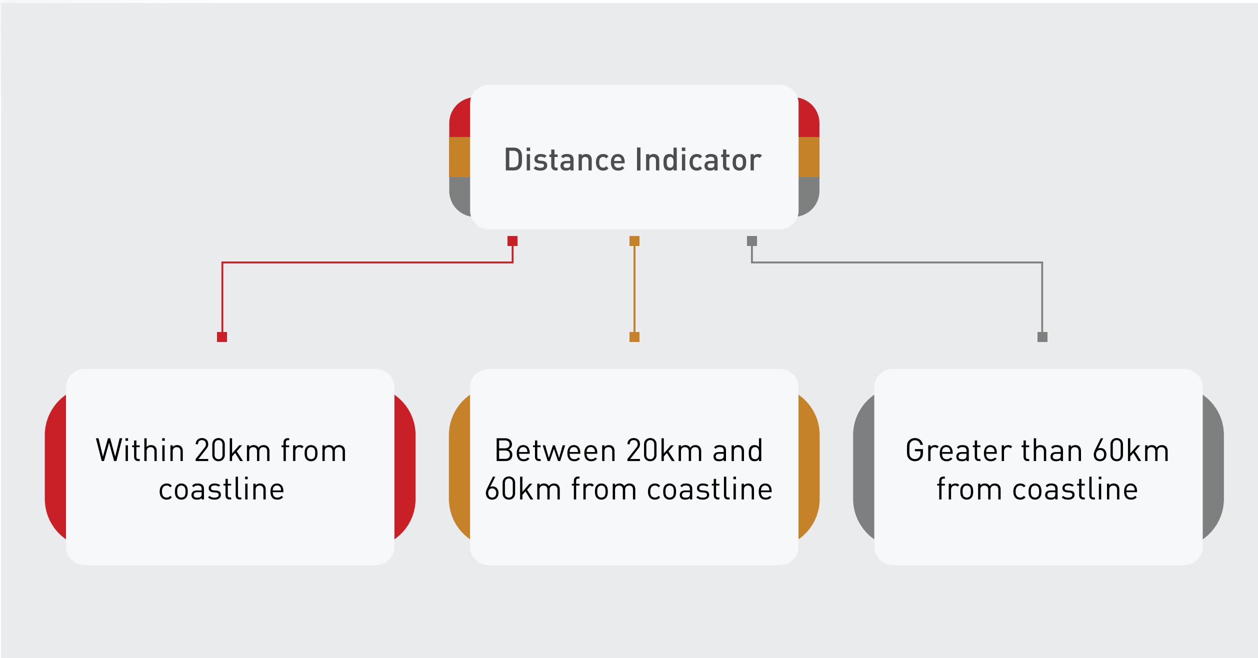
	No.	Indicators	Parameters	Score	Remarks
	2.	Type of PSS	▪ Gas-Insulated Substations (GIS) ▪ Air-Insulated Substations (AIS) – Indoor ▪ AIS (Indoor - 11 kV and Outdoor – 33 kV) ▪ AIS Outdoor	1 2 3 4	GIS is a compact indoor system that reduces substation areas compared to AIS. AIS is predominantly exposed to the outdoor environment
	3.	Building Standards/ Codes/Design Spec	▪ Single Storey ▪ Double Storey	1 4	Venerability of building, by their roof type
	4.	Type of Power Supply Source	▪ Ring Type (Double Source) ▪ Radial Type (Single Source)	1 4	Ring networks have a dual source of supply than radial networks with a single source
Distribution Lines	1.	Year of Commissioning	▪ Less than 30 years ▪ More than 30 years	1 4	Infrastructure outlived their services life are more at risk
	2.	Type of Supporting Structures/Poles	▪ UG (Under Ground) /Narrow Base Lattice Structure / H-Pole/ H, Rail/ Tower (Lattice) ▪ NBLS, JOIST, UG / Joist, Rail / Joist, Tower / Joist, H ▪ Joist / MIX ▪ PSC / Joist, PSC, Rail / Joist, Lattice / Joist, Tower	1 2 3 4	Poles with improved design, such as NBLA/ H-Pole are more resistant than PSC joist PSC
	3.	Span Length (m)	▪ Up to 40 m ▪ 40 to 50 m ▪ 50 to 60 m ▪ More than 60 m	1 2 3 4	Increased span length causes sagging that increases vulnerability
	4.	Failure History	▪ No ▪ Yes	1 4	Distribution line past failures increase the probable risk of breakdowns

	No.	Indicators	Parameters	Score	Remarks
Transmission Grid Sub Station [GSS]	1.	Type of GSS	▪ GIS ▪ AIS - Outdoor	1 4	GIS are compact indoor systems, while AIS is exposed to the outdoor environment
	2.	Year of Commissioning	▪ Less than 30 years ▪ More than 30 years	1 4	Infrastructure outlived their services life are more at risk
	3.	Failure History in Past Cyclones	▪ No ▪ Yes	1 4	Past failures increase the probable risk of breakdowns
	4.	Type of Power Supply Source	▪ Ring Type ▪ Radial Type	1 4	
Transmission – Lines	1.	Year of Commissioning	▪ Less than 30 years ▪ More than 30 years	1 4	Infrastructure outlived their services life are more at risk
	2.	Type of Circuit	▪ Double (Multiple Source) ▪ Single (Single Source)	1 4	Double circuits have multiple sources, making them less susceptible
	3.	Span Length (m)	▪ 400 kV line (<400 m) and 220 and 132 kV line <250 m ▪ 400 kV line (>400 m) and 220 and 132 kV line >250 m	1 4	Increased span length causes sagging that increases vulnerability
	4.	Failure History in Past Cyclones	▪ No ▪ Yes	1 4	Past failures increase the probable risk of breakdowns

The hazard vulnerability assessment (HVA) systematically investigates the possible harm that may arise from a possible disaster. Assessing vulnerability enables efficient pre-disaster planning and allocation of resources to the most susceptible site or infrastructure network. The ensuing sections discuss the vulnerability of the infrastructure to cyclone and flood hazards, taking into consideration the individual vulnerability of the infrastructure that was explained earlier.

3.4.1 Cyclone Vulnerability

The subsequent sections will comprehensively analyse the vulnerabilities in different power infrastructures caused by cyclones. The distribution and transmission substations and lines using the indicator-level vulnerability of the distribution and transmission network will be discussed. A distance indicator will be employed to assess the proximity of infrastructure to the coastline, which will categorize infrastructure as being within 20 km, between 20 km and 60 km, or greater than 60 km.



3.4.1.1 Distribution Substation

Approximately 30 percent of the vulnerable substations are situated in close proximity to the coast, within a distance of less than 20 km. The susceptibility of distribution substations located within the 20 km buffer zone is notably higher in Balasore, Jagatsinghpur and Kendrapada compared to other coastal districts. In addition, within a 20 to 60 km stretch, more than 22 percent of substations are classified as highly vulnerable, 11 percent as medium vulnerable and 2.6 percent as low vulnerable. Segregation based on the three distribution firms in the 20-km buffer indicates that approximately one-third (34%) of the substations belonging to TPNODL are at significant risk of being affected by cyclone winds near the coastline. The substation located in the Balasore district, which is under the jurisdiction of TPNODL, is the most vulnerable in this region. Similarly, the substations in Jagatsinghpur and Kendrapada, which fall under TPCODL, are also highly sensitive. Typically, the impact of high wind speeds is particularly pronounced in coastal regions within 0-60 km from the coastline. Evaluating the relative vulnerability of distribution substation maps in the coastal areas can assist in strategically planning and prioritizing repairs and upgrades for these substations. Table 3.3 provides an in-depth analysis of the vulnerability of the distribution substation. The following section offers indicator-level vulnerabilities that provide further insights into the matter.

Table 3.3: Distribution substations vulnerability

DISCOM/Districts	0-20 km			20-60 km			>60 km		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
TPCODL	-	9%	19%	5%	17%	10%	-	23%	17%
Angul	-	-	-	-	-	-	3%	73%	24%
Cuttack	-	-	-	-	-	-	-	57%	43%
Dhenkanal	-	-	-	-	-	-	-	39%	61%
Jagatsinghpur	-	3%	82%	-	-	15%	-	-	-
Kendrapada	-	-	79%	-	-	21%	-	-	-
Khordha	-	8%	3%	16%	51%	22%	-	-	-
Nayagarh	-	-	-	-	-	-	-	67%	33%
Puri	-	56%	27%	-	17%	-	-	-	-
TPNODL	-	-	34%	-	-	34%	-	3%	29%
Balasore	-	2%	93%	-	-	5%	-	-	-
Bhadrak	-	-	26%	-	-	71%	-	-	3%
Jajpur	-	-	8%	-	-	25%	-	-	67%
Keonjhar	-	-	-	-	-	27%	-	-	73%
Mayurbhanj	-	-	13%	-	-	56%	-	11%	20%
TPSODL	3%	11%	17%	2%	14%	35%	-	5%	13%
Gajapati	-	3%	3%	-	-	61%	-	12%	21%
Ganjam	4%	14%	22%	2%	19%	26%	-	2%	10%

3.4.1.2 Distribution Lines

The vulnerability of distribution lines arises from weak pole designs to which the circuit lines are attached. Around 80 percent of poles consist of PSC or Joist, both of which are vulnerable to high wind speeds. Approximately 12 percent of the total poles/towers are noted to have relatively less vulnerable designs, such as The Narrow-based Lattice Structure (NBLS,) H-Pole, Rail, or Tower (Lattice). Additionally, the increase of the span length also raises the vulnerability of the circuit line, with approximately 80 percent of the circuit lines having a span length of 70 m or more, amplifying its vulnerability. Compounding the issue is the ageing infrastructure, with approximately three-fourths of the circuit lines apparently being commissioned 30 years ago.

Table 3.4 depicts the vulnerability of the distribution line to cyclones. The vulnerability of the distribution line is determined by factors such as the design of the pole or tower on which the distribution lines are mounted, the length of the span, the year of commissioning and the history of failures. According to the vulnerability score, 23 percent of network lines classified as highly vulnerable are located within a 20 km radius of the coast. In comparison, more than 23 percent of high vulnerable circuit lines are situated between 20 and 60 km from the coastline. Districts such as Jagatsinghpur, Kendrapada and Balasore have highly vulnerable distribution lines within 0-20km.

Table 3.4: Distribution line vulnerability

DISCOM/Districts	0-20 km		20-60 km		>60 km	
	Medium	High	Medium	High	Medium	High
TPCODL	8%	23%	10%	10%	23%	24%
Angul	-	-	-	-	68%	32%
Cuttack	-	-	-	-	47%	53%
Dhenkanal	-	-	-	-	29%	71%
Jagatsinghpur	-	81%	-	19%	-	-
Kendrapada	-	87%	-	13%	-	-
Khordha	13%	6%	42%	30%	-	-
Nayagarh	-	-	-	-	60%	40%
Puri	48%	40%	12%	-	-	-
TPNODL	-	24%	-	30%	5%	42%
Balasore	-	96%	-	4%	-	
Bhadrak	-	35%	-	57%	-	8%
Jajpur	-	7%	-	23%	-	70%
Keonjhar	-	-	-	17%	-	83%
Mayurbhanj	-	10%	-	45%	15%	30%
TPSODL	9%	22%	12%	35%	7%	11%
Gajapati	1%	-	-	59%	23%	16%
Ganjam	12%	30%	17%	26%	2%	10%

3.4.1.3 Transmission Substations

Over 50 percent of highly vulnerable substations are located within the zone of greatest cyclone wind speeds, which is less than 20 km from the seashore. This indicates a higher probability of significant damage from strong wind events.

Coastal areas are particularly at risk due to the high percentage of air-insulated substations (AIS), which are prone to damage. Among these substations, 54 percent operate as ring distribution power systems and nearly one-fifth (19%) have a documented history of failures. Table 3.5 shows the vulnerability of the grid substation in the coastal divisions.

Table 3.5: Transmission grid substations vulnerability

Division	0-20 km			20-60 km		
	Low	Medium	High	Low	Medium	High
Balasore	-	14%	57%	-	14%	14%
Berhampur	-	-	75%	-	-	25%
Bhadrak	-	-	100%	-	-	-
Bhanjanagar	-	-	-	-	-	100%
Bhubaneswar	-	6%	31%	6%	25%	31%
Chatrapur	-	-	75%	-	25%	-
Choudwar	-	-	100%	-	-	-
Paradeep	-	-	50%	-	-	50%
Puri	-	-	100%	-	-	-

3.4.1.3 Transmission Line Vulnerability

Transmission vulnerabilities are evaluated for networks located within 60 km of the coastline.The vulnerability of a circuit line was evaluated based on three indicators: span length, double circuit/single circuit and age of infrastructure. Due to a lack of data, specific information about tower details was not available. However, it was observed that 32 percent of the lines have a span length greater than 250 m and 48 percent of the transmission lines are single circuits. At the aggregate level, more than nine percent of highly vulnerable transmission lines are located within 20 km of the coastline. Additionally, 12 percent of networks at high risk are located within 20 to 60 km from the coastline. Unlike distribution lines,three-quarters of the transmission lines operate within their expected lifespan. Table 3.6 provides a detailed description of the vulnerability of the transmission line.

Table 3.6: Transmission line vulnerability

Division	0-20 km			20-60 km		
	Low	Medium	High	Low	Medium	High
Central	20%	20%	2%	24%	20%	13%
North	32%	5%	18%	36%	0%	9%
South	29%	21%	21%	14%	0%	14%

3.4.1.5 Indicator-wise Vulnerability

This section provides a comprehensive analysis of the specific characteristics and conditions of the infrastructure, such as its age, kind and design, and examines how these factors impact its vulnerability. It addresses both T&D networks.

3.4.1.5.1 Vintage infrastructures: Distribution Network

The existing electrical infrastructure must prioritize reducing its vulnerability to cyclone. Within 20 km from the coast, around 24 percent of the substations in Ganjam were installed more than 30 years ago, making them more susceptible to damage. Between 20 and 60 km, approximately 19% and 27% of substations in the Khordha and Ganjam districts, respectively, were installed over 30 years ago. With the increasing occurrence of strong winds, as documented in the literature research and zoning maps, there is an urgent need to upgrade these substations. More details can be found in Table 3.7.

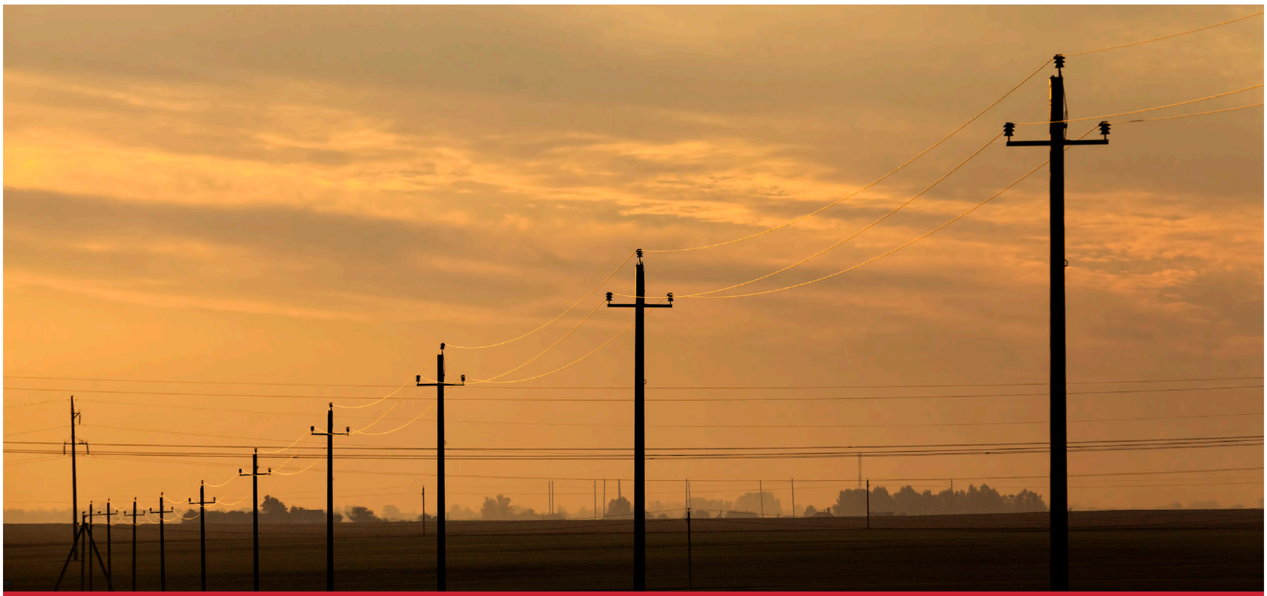


Table 3.7: Vulnerability of substation w.r.t service life and its distance from seacoast

DISCOM/Districts	0-20 km		20-60 km		>60	
	Less than 30 Years	More than 30 Years	Less than 30 Years	More than 30 Years	Less than 30 Years	More than 30 Years
TPCODL	23%	2%	26%	6%	28%	16%
Angul	0%	0%	0%	0%	77%	23%
Cuttack	0%	0%	0%	0%	60%	40%
Dhenkanal	0%	0%	0%	0%	63%	37%
Jagatsinghpur	75%	0%	25%	0%	0%	0%
Kendrapada	78%	0%	22%	0%	0%	0%
Khordha	6%	3%	72%	19%	0%	0%
Nayagarh	0%	0%	0%	0%	52%	48%
Puri	84%	6%	9%	0%	0%	0%
TPNODL	35%	0%	27%	0%	38%	0%
Balasore	97%	0%	3%	0%	0%	0%
Bhadrak	24%	0%	76%	0%	0%	0%
Jajpur	8%	0%	18%	0%	74%	0%
Keonjhar	0%	0%	26%	0%	74%	0%
Mayurbhanj	15%	0%	33%	0%	52%	0%
TPSODL	18%	20%	29%	21%	8%	4%
Gajapati	5%	5%	91%	0%	0%	0%
Ganjam	21%	24%	13%	27%	11%	5%

Radial or Ring Operation: Distribution Network

The Ring distribution system is more resilient than the radial distribution system. Unfortunately. the power distribution in Odisha accounts for only 16 percent with a ring system, with less than 5 percent of this ring distribution located within 20 km of the coastline. The rest of the distribution operates on a radial system. According to Table 3.8, Puri, Ganjam, Jagatsinghpur and Kendrapada have installed more than 10 percent of the ring system in the 0-20km stretch, while the Khordha district exhibits the highest degree of ring distribution compared to other coastal districts within the 0-60km stretch.

Table 3.8: Vulnerability of ring/radial substations w.r.t distance from seacoast

DISCOM/Districts	0-20 km		20-60 km		>60	
	Ring	Radial	Ring	Radial	Ring	Radial
TPCODL	4%	24%	10%	13%	8%	41%
Angul	0%	0%	0%	0%	11%	89%
Cuttack	0%	0%	0%	0%	38%	62%
Dhenkanal	0%	0%	0%	0%	4%	96%
Jagatsinghpur	13%	77%	11%	0%	0%	0%
Kendrapada	11%	63%	1%	25%	0%	0%
Khordha	3%	10%	44%	43%	0%	0%
Nayagarh	0%	0%	0%	0%	5%	95%
Puri	10%	78%	0%	12%	0%	0%
TPNODL	3%	28%	2%	26%	2%	39%
Balasore	9%	86%	0%	4%	0%	0%
Bhadrak	4%	17%	10%	69%	0%	0%
Jajpur	0%	8%	0%	18%	0%	74%
Keonjhar	0%	0%	3%	21%	5%	71%
Mayurbhanj	6%	10%	2%	31%	13%	38%
TPSODL	13%	15%	12%	44%	2%	14%
Gajapati	0%	19%	35%	47%	0%	0%
Ganjam	16%	15%	7%	44%	3%	17%

3.4.1.5.2 Type of Substation: Distribution Network

The majority of distribution substations are AIS, and they are at risk due to strong winds. Gas-insulated substations (GIS) make up less than 6 percent of the total, as shown in the details provided in Annexure Table A.1. Additionally, Annexure Table A.2 indicates whether the substation is a single- or multi-story building, which also serves as an indicator of vulnerability. Multi-story buildings are more prone to hazards than single-story buildings. It is worth noting that TPCODL and TPSODL do not have any multi-story substations along their entire buffer range from the coast (0-20 km, 20-60 km, >60 km). However, four percent of the TPNODL's substations are multi-storeyed and located within the 0-20 km buffer zone from the coast.

3.4.1.5.3 Design Vulnerability of Utility Pole: Distribution Network

The vulnerability of a line network is mostly determined by the poles on which the distribution lines are installed. Well-designed poles are more resistant to cyclone winds, from mild to extreme. However, 87 percent of poles are either PSC or Joist designs, making them vulnerable to high wind speeds. Furthermore, 28 percent of structures of these designs are in areas with high cyclone wind speeds. The districts of Jagatsinghpur, Ganjam, Kendrapada, Balasore and Puri have the highest number of vulnerable poles. To address this issue, advanced designs such as NBLS, H-Pole, Rail and Tower are currently being installed in the districts of Ganjam, Gajapati and Khordha. Table 3.9 provides a more comprehensive set of data regarding the vulnerability of utility poles.

Table 3.9: Vulnerability of supporting poles of distribution line

DISCOM/Districts	0-20 km			20-60 km			>60 km		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
TPCODL	1%	1%	27%	12%	0%	20%	3%	0%	37%
Angul	0%	0%	0%	0%	0%	0%	33%	3%	64%
Cuttack	0%	0%	0%	0%	0%	0%	0%	0%	100%
Dhenkanal	0%	0%	0%	0%	0%	0%	0%	0%	100%
Jagatsinghpur	3%	0%	82%	0%	0%	15%	0%	0%	0%
Kendrapada	0%	0%	79%	0%	0%	21%	0%	0%	0%
Khordha	0%	4%	7%	40%	1%	49%	0%	0%	0%
Nayagarh	0%	0%	0%	0%	0%	0%	0%	0%	100%
Puri	2%	0%	80%	0%	0%	17%	0%	0%	0%
TPNODL	1%	0%	33%	3%	0%	31%	1%	0%	31%
Balasore	2%	0%	93%	0%	0%	5%	0%	0%	0%
Bhadrak	3%	0%	24%	15%	0%	56%	0%	3%	0%
Jajpur	0%	0%	8%	3%	0%	22%	0%	0%	67%
Keonjhar	0%	0%	0%	0%	0%	27%	0%	0%	73%
Mayurbhanj	0%	0%	13%	0%	0%	56%	4%	0%	28%
TPSODL	7%	0%	25%	3%	0%	48%	3%	0%	14%
Gajapati	0%	0%	6%	0%	0%	61%	9%	0%	24%
Ganjam	9%	0%	32%	4%	0%	43%	1%	0%	11%
PSED	0%	0%	0%	0%	0%	100%	0%	0%	0%

The vulnerable length of the circuit at TPCODL is 115 km (4%) at distances ranging from 20 to 60 km from the seacoast. Vulnerability is observed in PSC, H, PSC Rail, Lattice and Tower joists within 0-20 km from the seacoast, specifically in the Jagatsinghpur (20 km), Kendrapada (43 km) and Khordha (61 km) areas. The total length of the circuit vulnerable to TPNODL is 642 km. It spans across various districts, including Balasore (16 km), Bhadrak (149 km), Jajpur (51 km), Keonjhar (101 km) and Mayurbhanj (324 km). The total length of the circuit vulnerable to TPSODL is 742 km, with 262 km in the Gajapati district and 480 km in the Ganjam district. Annexure Tables A.3 and A.4 list the length of The vulnerable circuit at TPCODL is 115 km (4%) at distance from the seacoast based on the year of commissioning and the length in kilometres of the line that failed during past hazards based on its distance from the seacoast.

3.4.1.5.4 Type of Substation (AIS/GIS): Transmission Network

More than 80 percent of transmission substations situated within a range of 0-60 km from the coastline is AIS and considered more vulnerable to damage than GIS insulation. Table 3.10 provides more details on the substation type and its buffer location.

Table 3.10: Type of AIS/GIS transmission substation

Division	0-20 km		20-60 km	
	GIS	AIS	GIS	AIS
Balasore	0%	71%	0%	29%
Berhampur	0%	75%	0%	25%
Bhadrak	0%	100%	0%	0%
Bhanjanagar	0%	0%	0%	100%
Bhubaneswar	0%	38%	25%	38%
Chatrapur	0%	75%	0%	25%
Choudwar	0%	100%	0%	0%
Paradeep	0%	50%	0%	50%
Grand total amount	0%	100%	0%	0%

3.4.1.5.5 Type of Radial/Ring Transmission: Transmission Network

Table 3.11 depicts the type of transmission substation in various districts and its location from the coastline. Approximately 27 percent of transmission substations located within 0-20 km from the coastline are radial type, which is considered to be more vulnerable compared to the ring system. On the other hand,ring distribution has been implemented in over 50 percent of network distributions

Table 3.11: Type of radial/ring transmission

Division	0-20 km		20-60 km	
	Ring	Radial	Ring	Radial
Balasore	29%	43%	29%	29%
Berhampur	50%	25%	0%	25%
Bhadrak	0%	100%	0%	0%
Bhanjanagar	0%	0%	100%	100%
Bhubaneswar	25%	13%	31%	38%
Chatrapur	75%	0%	25%	25%
Choudwar	0%	100%	0%	0%
Paradeep	0%	50%	0%	50%
Puri	0%	100%	0%	0%

3.4.1.5.6 Span Length: Transmission Network

Lengthening the span of the transmission line results in an increased wind load. One way to minimize the impact of cyclones on the transmission system is by reducing the span length. Approximately seven percent of transmission lines, primarily located in the central and southern divisions, have a span length exceeding 250 m. Table 3.12 gives more information on the various transmission divisions and their associated span length with their location from the sea.

Table 3.12: Span length - transmission line w.r.t distance from seacoast

Division	0-20 km		20-60 km		>60 km	
	Up to 250 m	Avg. Span Length >250, >400 m	Up to 250 m	Avg. Span Length >250, >400 m	Up to 250 m	Avg. Span Length >250, >400 m
Central	12%	5%	16%	8%	36%	22%
North	13%	6%	14%	2%	43%	22%
South	7%	7%	3%	3%	55%	25%
West	0%	0%	0%	0%	74%	26%

3.4.2 Flood Vulnerability

The flood vulnerability analysis shows that the substations situated in places with high water depths are highly susceptible. The 33/11 kV substations situated in Chakada, Rajnagar, Bartana, Randia, Ranipokhari and Merda (Anla) are at significant risk due to high water levels in these regions. This poses a potential threat to the access roads leading to the substations, as they might face restrictions due to water accumulation in the nearby regions.Overlaying the road network can offer valuable insights into which parts of the road network are at risk of flooding during high flood events. The flood zonation maps, as displayed in Section 3.2, can be utilized for planning and installing assets, providing valuable information on the anticipated flood levels in specific locations to enable informed decision-making. Furthermore, elevating the plinth levels of the poles and other assets in accordance with the water depths can help mitigate the impact of flooding.

3.4.3 Multi-Hazard Vulnerability

In accordance with the United Nations Disaster Risk Reduction (UNDRR) framework established in 2015, it is crucial to incorporate comprehensive evaluations of multiple hazards and sectors to enhance risk reduction strategies. The term 'multi-hazard' refers to situations in which hazardous events might occur independently, at the same moment, in a chain reaction, or gradually over time, considering the possible interconnected consequences (CDRI, 2023).Assets related to power infrastructure that are vulnerable to both cyclones and floods will exhibit a higher rate of multi-hazard risk. The vulnerability of each component of the network to hazards such as cyclones and floods is calculated using a comprehensive vulnerability index (VI), where all indicators are given equal importance.

$$VI = \sum_{i}^{n} W_i * V_i$$

In the above equation, VI represents the VI for a certain asset, W is a weight with a value of 1, V is the score of a variable or indicator under criterion i, and n represents the total number of criteria. The results of the multi-hazard vulnerability assessment are displayed in Tables 3.13 and 3.14. According to Table 3.13, the Rajnagar 33/11 kV substation in the Kendrapada district is extremely vulnerable to cyclones and floods. Table 3.14 displays three distribution lines: the Bhograi grid to Bartana PSS (primary substation), the Bhograi grid to Dehurda PSS and the Bhograi PSS to Jagannathpur PSS in the Balasore district. These distribution lines are highly vulnerable to both cyclone and flood hazards.

Table 3.13: Distribution substations' multi-hazard vulnerability

Name of Distribution Substation	District	DISCOM	Cyclone Vulnerability	Flood Vulnerability	Multi-hazard
Rajnagar 33/11 kV s/s	Kendrapad	TPCODL	High	High	High

Table 3.14: Distribution lines' multi-hazard vulnerability

Name of the Line (From)	Name of the Line (To)	District	Discom	Cyclone Vulnerability	Flood Vulnerability	Multi-hazard
Bhograi Grid (tapping at near Nahanjara NH 60)	Bartana PSS	Balasore	TPNODL	High	High	High
Bhograi Grid	Dehurda PSS	Balasore	TPNODL	High	High	High
Bhograi PSS	Jagannathpur PSS	Balasore	TPNODL	High	High	High

3.5. Prioritization of Power components

Considering current conditions where various power infrastructures are vulnerable to multiple hazards, it is essential that any proposed investment to enhance or expand the infrastructure must be supported by robust technical safeguards. Developing a prioritized action plan by assessing the significance of power assets would certainly aid in achieving this goal. The subsequent sections will focus on identifying different critical infrastructures and prioritizing these assets to develop strategies and action plans.

3.5.1 Identification of Critical Components

Critical power lines play an important role in ensuring vital services such as water supply, telephone communication, healthcare facilities, transportation and emergency response, as well as the operation of district administration buildings. During cyclones or floods, the lack of electricity jeopardizes these essential services and significantly impedes rescue efforts. It is essential to identify the primary T&D lines and substations that supply power to these essential services to recommend renovation or retrofitting based on the new design and updated wind map.

Identifying critical elements is a primary task in this study. For this, the first step involves identifying power assets that offer important services, such as critical lines and substations. Secondly, individual power components, such as poles, conductors and towers susceptible to cyclone damage, are mapped. Merging these two would facilitate the identification of crucial elements.

3.5.2 Critical Assets Based on Importance

Lines and substations providing essential services are classified into various categories: 1, 2 and 3. This would facilitate the process of mapping critical lines and PSS/GSS (grid substation).

- Category-1: Feeding to essential services viz. medical, water supply pumping station, cyclone shelters (schools/colleges), food warehouse, district headquarters, police station, telecom towers, fire stations, railway stations, airport, bus stand, defence, etc.

- Category-2: Based on loading (trunk lines).

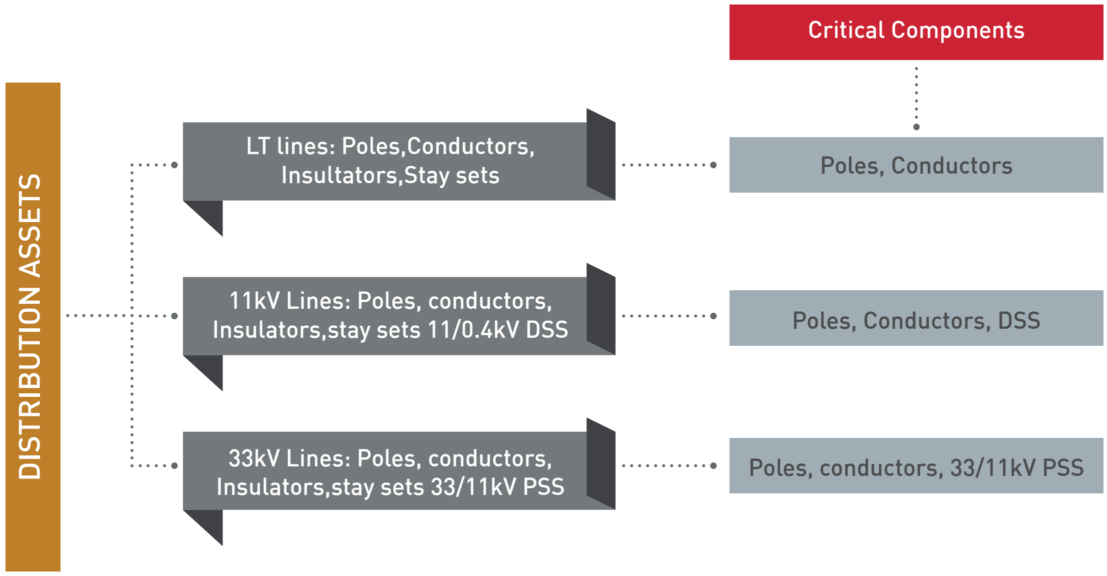
- Category-3: Based on the feeding arrangement of substations viz. radial or ring system (to meet N-1 contingency criteria).

3.5.3 Critical Assets Based on Risk

During disasters, overhead wires in the T&D system are more prone to damage than substations. The four main elements of power lines, including towers/poles, insulators, hardware fittings and conductors, are particularly susceptible to damage during disasters. The structures of outdoor substations are particularly at-risk during cyclones, and the plinths of PSS located below the designated flood level are also highly vulnerable. Figures 3.9 and 3.10 illustrate the power components that are highly vulnerable and should be given priority for reinforcement to withstand the risks posed by many hazards.

3.5.3.1 Critical Assets at Risk in Distribution System

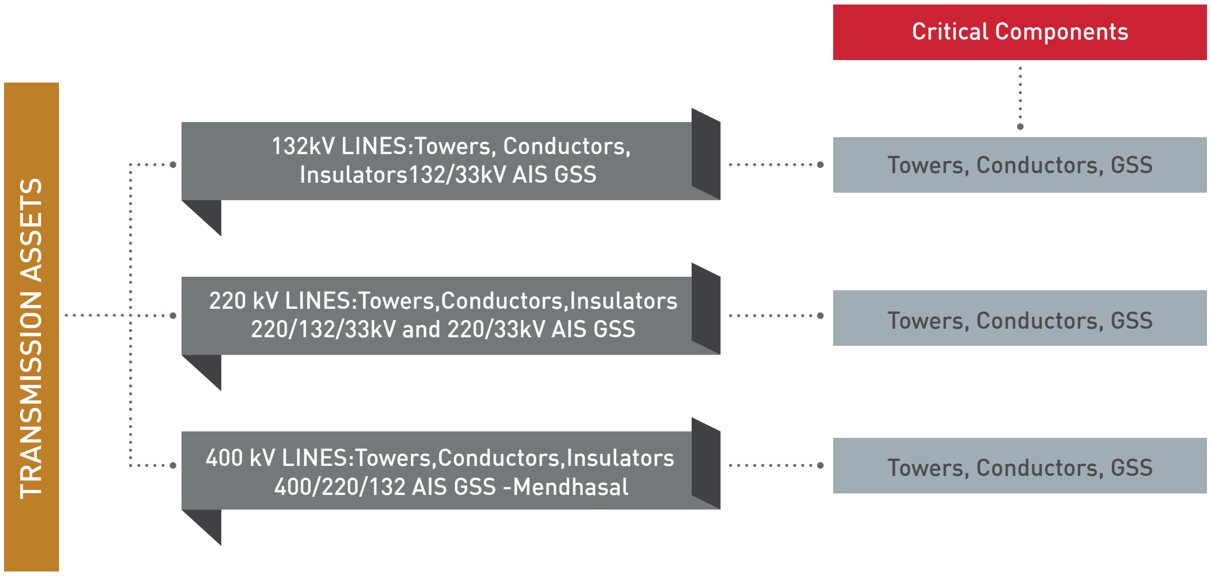
Figure 3.9: Distribution system critical assets



Among the distribution assets, such as the low-tension line, 11 kV line and 33 kV lines, there are critical components that are vulnerable to the identified hazards. The critical components for the low-tension lines include poles and conductors. For the 11 kV lines, the critical components are poles, conductors and distribution substations (DSS). In the case of 33 kV lines, the critical components are poles, conductors and a 33/11 kV PSS.

3.5.3.2 Critical Assets at Risk in Transmission System

Figure 3.10: Transmission system critical assets



In the transmission assets comprising 123 kV, 220 kV and 400 kV lines, the most critical components are the towers, conductors and GSS (grid substation). Based on the analysis, the following assets in the T&D lines have been recognized as critical. To update and reinforce all current infrastructure in areas impacted by cyclones according to updated regulations and revised wind patterns, a lengthy interruption of the power supply may be necessary, potentially disrupting the smooth distribution of electricity. Prioritizing this modification or strengthening of transmission lines will be based on the failure history of existing lines and the identification of vital lines in cyclone-prone areas. This prioritization is done through design considerations, particularly if repeated failures occur in a specific line.

Tables 3.15 and 3.16 give the abstracts of identified critical lines and substations under OPTCL, TPCODL, TPNODL and TPSODL. These lines are also categorized based on their distance from the coast: lines within 0-20 km, lines within 20-60 km and lines beyond 60 km. Figures 3.11 to 3.14 show the critical and non-critical distribution assets for a 50-year return period with a 3-second gust speed for TPNODL, TPSODL and TPCODL.

Table 3.15: Critical lines in OPTCL, TPCODL, TPNODL and TPSODL

Voltage Level (kV)	OPTCL			TPCODL			TPNODL			TPSODL		
	0-20 km	20-60 km	>60 km	0-20 km	20-60 km	>60 km	0-20 km	20-60 km	>60 km	0-20 km	20-60 km	>60 km
400	0	0	0	-	-	-	-	-	-	-	-	-
220	1	1	0	-	-	-	-	-	-	-	-	-
132	15	4	0	-	-	-	-	-	-	-	-	-
33	-	-	-	83	25	38	72	52	13	42	61	15

Table 3.16: Critical GSS and PSS in OPTCL, TPCODL, TPNODL and TPSODL

Voltage Level (kV)	OPTCL			TPCODL			TPNODL			TPSODL		
	0-20 km	20-60 km	>60 km	0-20 km	20-60 km	>60 km	0-20 km	20-60 km	>60 km	0-20 km	20-60 km	>60 km
400	0	0	0	-	-	-	-	-	-	-	-	-
220	4	1	0	-	-	-	-	-	-	-	-	-
132	8	1	0	-	-	-	-	-	-	-	-	-
33	-	-	-	63	56	42	69	33	16	40	39	13

Figure 3.11: TPNODL 33 kV system map: critical/non-critical (50-year return period-3-second gust speed)

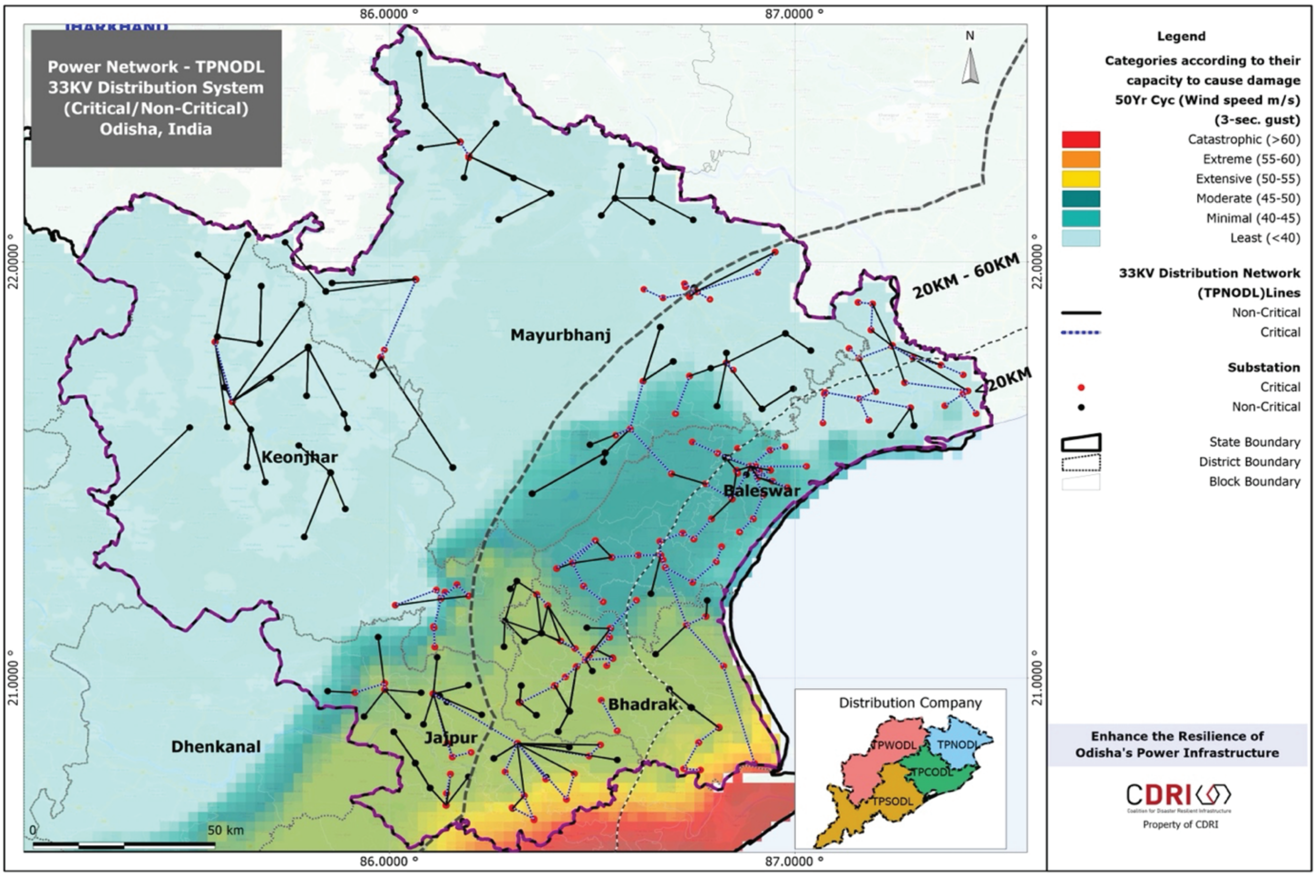


Figure 3.12: TPSODL 33 kV system map: critical/non-critical (50-year return period-3-second gust speed)

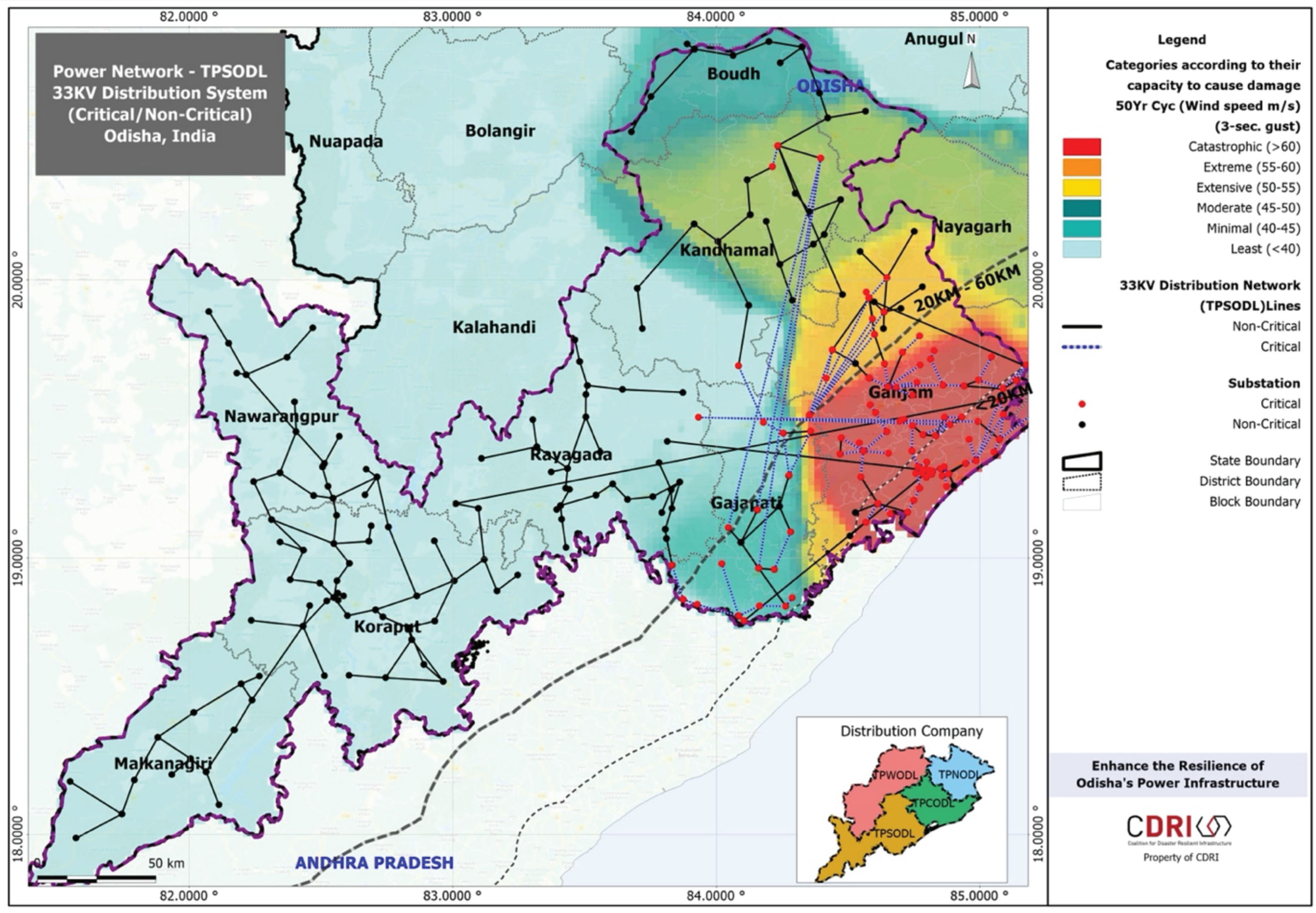


Figure 3.13: TPCODL 33 kV system map: Critical/non-critical (50-year return period-3-second gust speed

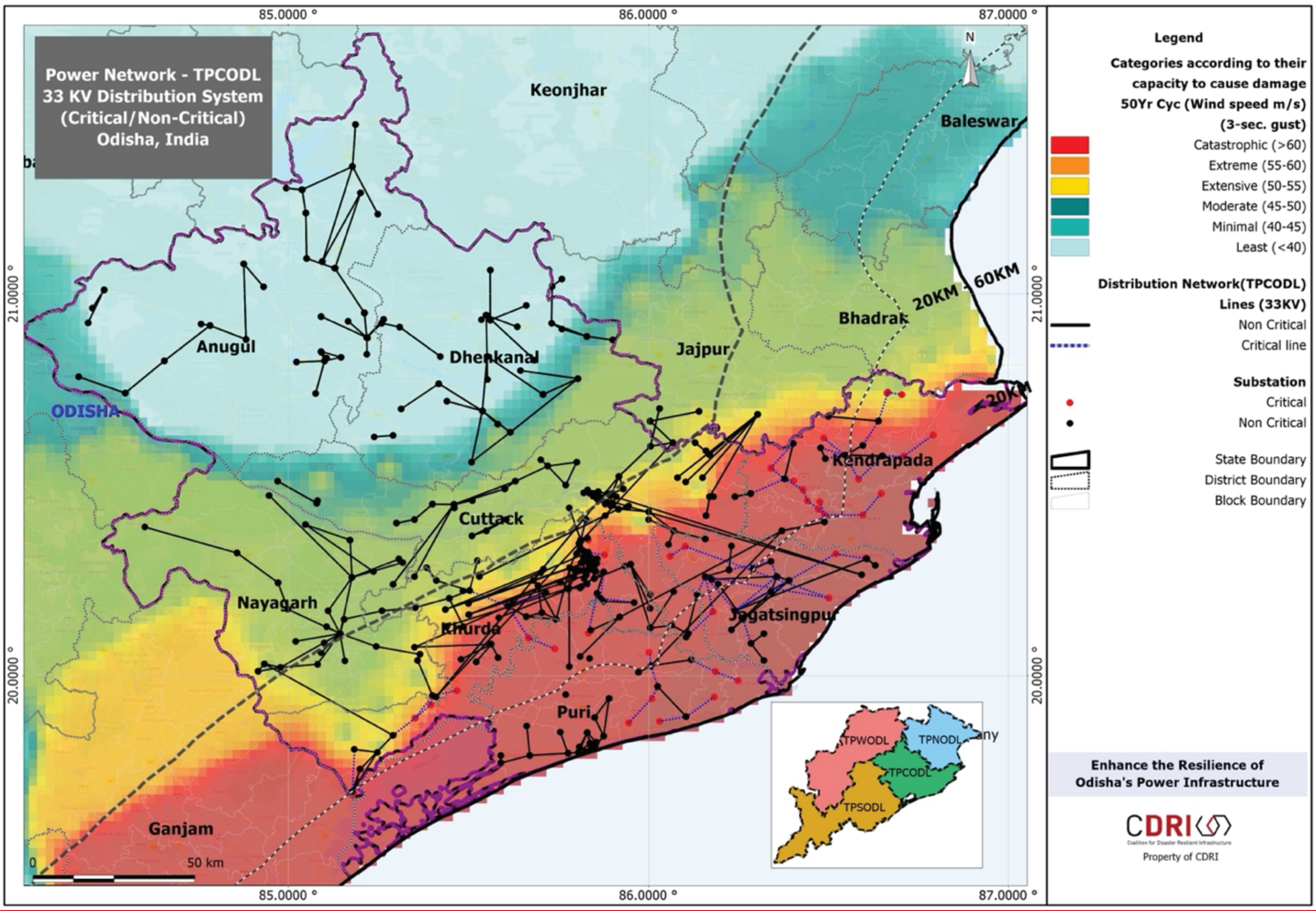
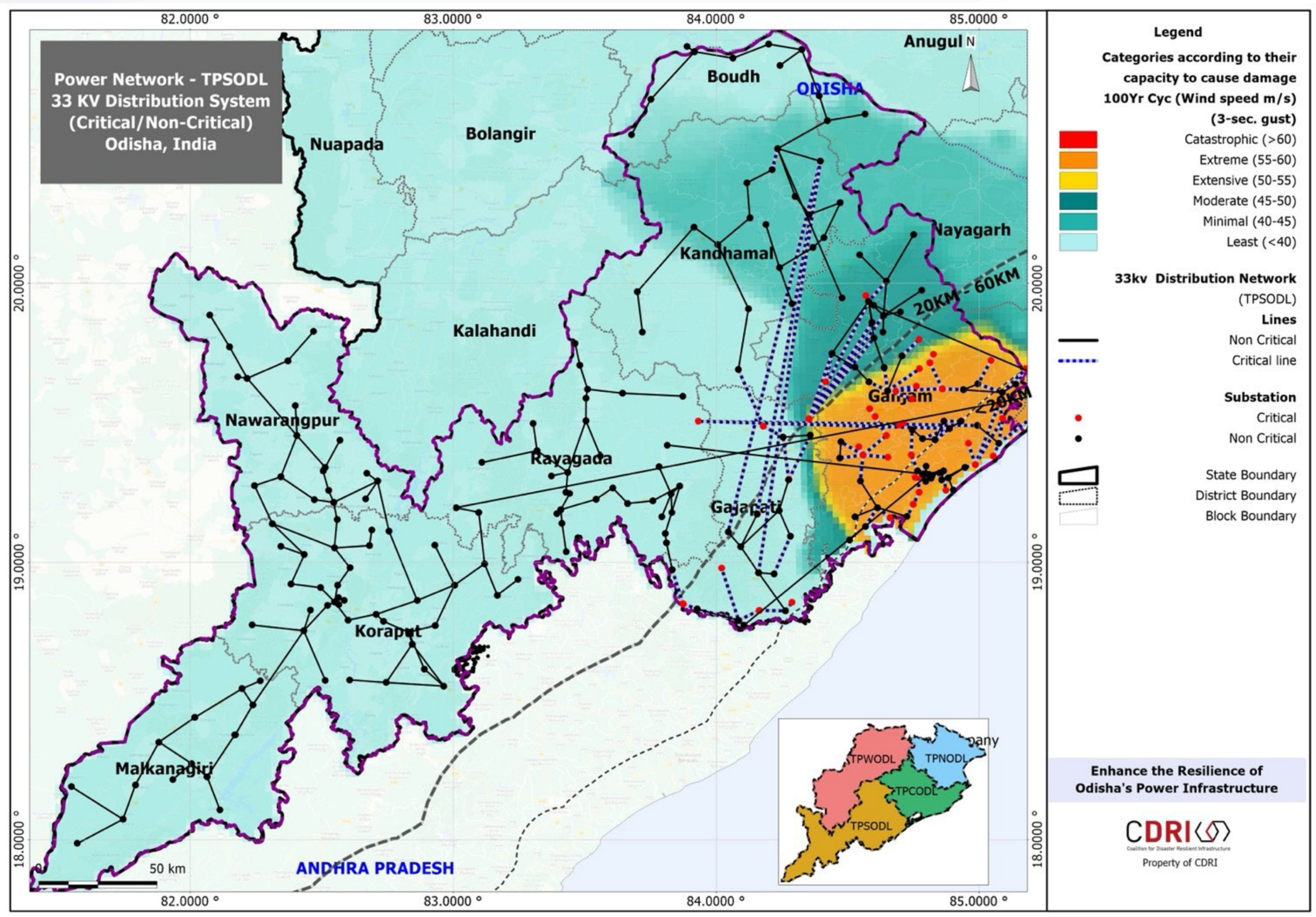


Figure 3.14: TPNODL 33 kV system map: critical/non-critical (100-year return period-3-second gust speed)



3.5.4 Prioritization of Critical Components

According to the cyclone zonation map created in this study, it is observed that the impact of cyclonic storms is predominantly experienced within a zone of about 60 km from the coastline. Given the significant financial burden and extended periods of power loss, replacing or renovating all the current electricity infrastructures in this region is impractical. Therefore, infrastructure prioritizing is based on the criticality, importance and vulnerability of the line or PSS. By leveraging the vulnerability identified in Section 3.4 and the criticality of power components identified in Section 3.5, a matrix approach is employed for prioritization. The matrix shown in Table 3.17 is used to prioritize the components of lines and PSS.

Table 3.17: Prioritization matrix

Criticality	Vulnerability	Distance from Seacoast	Priority
Yes	High	High	1
Yes	High	Medium	2
Yes	High	Low	3
Yes	Medium	High	2
Yes	Medium	Medium	3
Yes	Medium	Low	4
Yes	Low	High	3
Yes	Low	Medium	4
Yes	Low	Low	4
No	High	High	2
No	High	Medium	3
No	High	Low	4
No	Medium	High	3
No	Medium	Medium	4
No	Medium	Low	4
No	Low	High	3
No	Low	Medium	4
No	Low	Low	4

Table 3.18 summarizes the 33 kV line and substations, categorizing them based on their criticality and vulnerability to multiple hazards. Priority 4 signifies that no further reinforcement is necessary, whereas Priority 1 implies a greater need for improving power facilities.

Table 3.18 Prioritization of 33 kV lines and PSS (abstract)

DISCOMS	Priority 1		Priority 2		Priority 3		Priority 4	
	Line	PSS	Line	PSS	Line	PSS	Line	PSS
TPCODL	52	18	62	59	45	74	199	171
TPNODL	71	5	59	62	34	44	62	115
TPSODL	34	2	59	46	26	39	13	20

Table 3.19: Prioritization of 11 kV lines

DISCOMS	Priority 1	Priority 2	Priority 3	Priority 4
TPCODL	138	333	91	0
TPNODL	144	133	101	0
TPSODL	146	137	92	24

Table 3.19 provides a summary of 11 kV lines. These have been categorized based on their importance and vulnerability to multiple risks. Prioritization of transmission lines and GSS are given in Table 3.20. A comprehensive list of Transco-wise and DISCOM-wise information is provided in the Annexures.

Table 3.20: Prioritization of transmission lines and GSS

Assets	Priority 1		Priority 2		Priority 3		Priority 4	
	Line	PSS	Line	PSS	Line	PSS	Line	PSS
400	0	0	0	0	0	0	11	0
220	1	4	0	1	10	1	83	3
132	3	7	9	10	33	8	228	4

4 Recommendations

Hazard Zonation

The frequency of cyclones varies across different coastal areas, particularly for the coastal states. Areas experiencing more frequent cyclones face a higher annual risk of damage, even if they have the same design wind speed as other locations. Hence, it is crucial to prioritize wind zonation for the coastal states. Conducting an assessment of vulnerability and critical power infrastructure is necessary to strengthen it based on micro wind zonation. The mapping of flood zonation and vulnerable assets is essential for determining priorities for necessary strengthening, much like wind zonation.

Systematic Recording of Damage Assessment

The current situation is that information regarding damage to infrastructure due to various disasters such as cyclones and floods is scattered or not consolidated. Some data is available in spatial format, while most of it is in attribute format. It is important that this data is collected and stored in the geographic information system format in a central repository or with utilities. By using spatially informed damaged assets, one can improve design inventiveness and preparedness for future catastrophes. It is also advisable for future disaster assessments to conduct a systematic spatial assessment in accordance with the post-disaster need assessment frameworks laid out by the Global Fund for Disaster Risk Reduction (GFDRR).

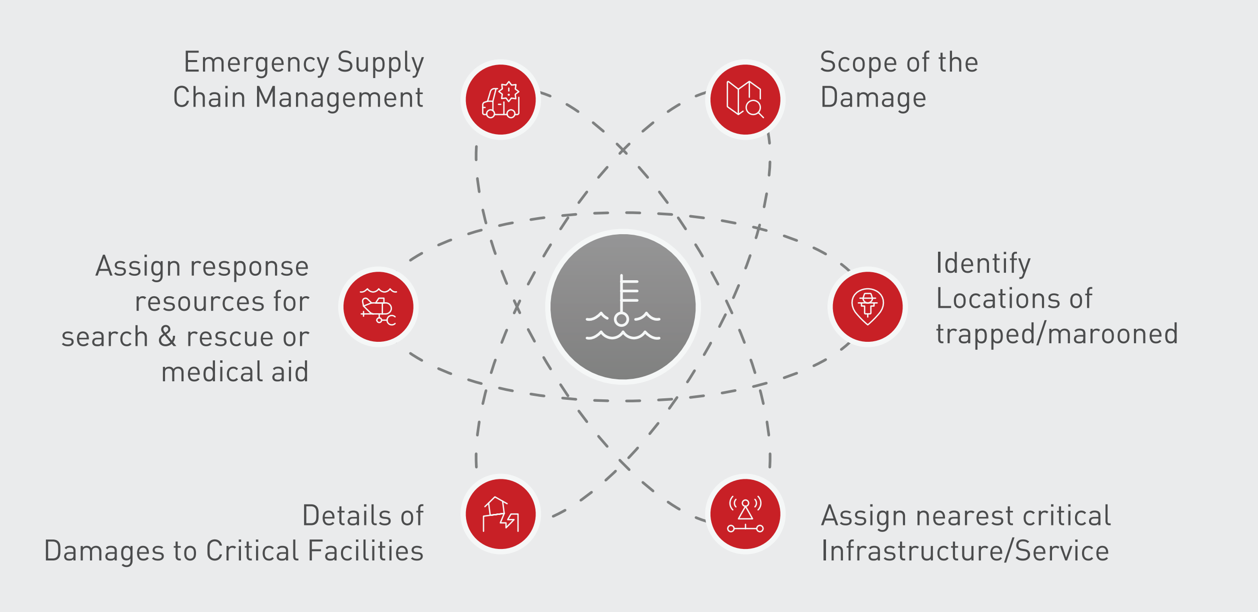
Spatial Asset Inventory and Update

An inventory of spatial assets for the power transmission network in Odisha is currently accessible. The DISCOMs are in the process of planning and conducting digital asset inventories for their distribution assets. The geographical database will be used as a digital tool for monitoring, planning and decision-making. This approach will ensure that everything, from regular maintenance and fixes to planning for new assets, is tracked in a spatial repository. It is important to standardize and conduct the annual data inventory audit on a regular basis.

User-friendly Web-Geographic Information System Application

Disaster risk reduction and management increasingly depend on geospatial systems for forecasting, issuing warnings before disasters and swiftly deploying assets and human resources. Power utilities can collect and store a large amount of data that can be readily accessed and analyzed effectively. One of the key strengths of a geographic information system lies in its ability to integrate data and prepare it for analysis or modelling, apart from tying together data from various sources, which makes it an important tool for planning and decision-making. With a geographic information system, users can display legends of all layers displayed on the map, representing each layer with a symbol and colour, along with the layer's name in a list. Even those without prior knowledge of geographic information system applications can use this user-friendly application by overlaying the required layers.

The flood early warning system and anemometers installed at micro and localized levels through the Internet of Things (IoT) devices can provide situational awareness about rainfall, canal water levels and street inundation status. It is crucial for the control room EoC (as given in DMP of DISCOM) to have well-trained staff who can effectively utilize this system. Additionally, WebGIS for disaster management can provide the following types of information through any device connected to the internet:



Additional services can also be provided as needed. Such platforms can further visualize the locations of assets and human resources using mobile phone-based tracking systems. Additionally, road connectivity tracking solutions are available from data providers such as Google and Waze.

The DISCOMs have other data sets and are developing a platform to help EoC. This can include attribute data on critical infrastructure. It will be advisable to use some of the municipal geographic information system layers within the proposed WebGIS, and all data processing can be done on cloud servers. The following base layers are essential for WebGIS:

- Topographic and drainage maps
- Geographic information system-mapped assets
- Population distribution maps
- Road, S&D, water supply, electricity, communication network
- Critical infrastructure, including hospitals, police and fire stations, pumping stations, bridges and government offices with attribute data
- Dilapidated/vulnerable power assets
- Incident database of all major cyclones, storm flood events (areas/locations), fires, building/bridge collapses and other disasters

- Hazard, vulnerability (infrastructure, social) and risk maps
- IoT sensor locations with real-time data
- Key resources tracking maps (fire engines, portable pumps, vehicle-mounted ladders, etc.)
- Responder tracking maps
- A map library of simulations for different intensities of hazards and quantitative data from simulations

Prioritization of Power Components Based on Criticality and Vulnerability

a) Utilities need to focus immediately on lines and substations selected in Priority 1, as analyzed in this report, based on their criticality and vulnerability. The OPTCL and respective DISCOMs may further investigate this in the field at the micro level before making any investment proposal.

b) The following lines and substations are identified under Priority 1:

- 52, 71 and 34 of 33 kV lines are selected under TPCODL (Tata Power Central Odisha Distribution Limited), TPNODL (Tata Power Northern Odisha Distribution Limited) and TPSODL (Tata Power Southern Odisha Distribution Limited), respectively.
- 18, 5 and 2 of primary substations are selected under TPCODL, TPNODL and TPSODL, respectively.
- One 220 kV and three 132 kV lines are identified along with four 220 kV grid substations (GSS) and seven 132 kV GSS under OPTCL in Priority 1.

c) It is recommended after Priority 1, lines and substations selected under Priority 2 and Priority 3 may be verified at the field level by respective utilities before any investment proposal.

Limitations

a) For hazards (cyclone and flood) assessment: Past geographic information system base data availability was challenging in this study. Hence, the consultant team used other public domain official sources such as IMD and base cyclone track archives to understand historical records of cyclones and floods in Odisha to resolve this.

- For cyclones and floods, baseline data is unavailable for developing zonation maps. Hence, open-source data is used at the best possible resolution.
- The non-availability of geo-referenced data exposure data sets related to power infrastructure assets (33 kV, 11 kV and low-tension lines). These electrical lines and poles are most affected during disasters and are critical. For substations such as 132 kV, 220 kV and 400 kV, the network consultant team has extracted data from the single line diagram (SLD) received from DISCOMs and Odisha Power Transmission Corporation Limited.

2. The Ganjam district SRTM data is unavailable and therefore flood assessment has not been done for this coastal district. In Puri district, Puri city has been extensively used for flood assessment.
3. For understanding, first-, second- and third-order risk data was only available for the Cyclone Fani disaster. No other hazard-specific details were available.
4. The flood exposure of transmission and distribution substations cannot be accurately depicted due to the low resolution of the district-level map. Therefore, it is advisable to conduct a thorough evaluation at the regional or local level in the future.

Annexure 1: Cyclone Zonation Maps

Figure A1: Cyclone zonation map (maximum sustain wind speed 50-year return period)

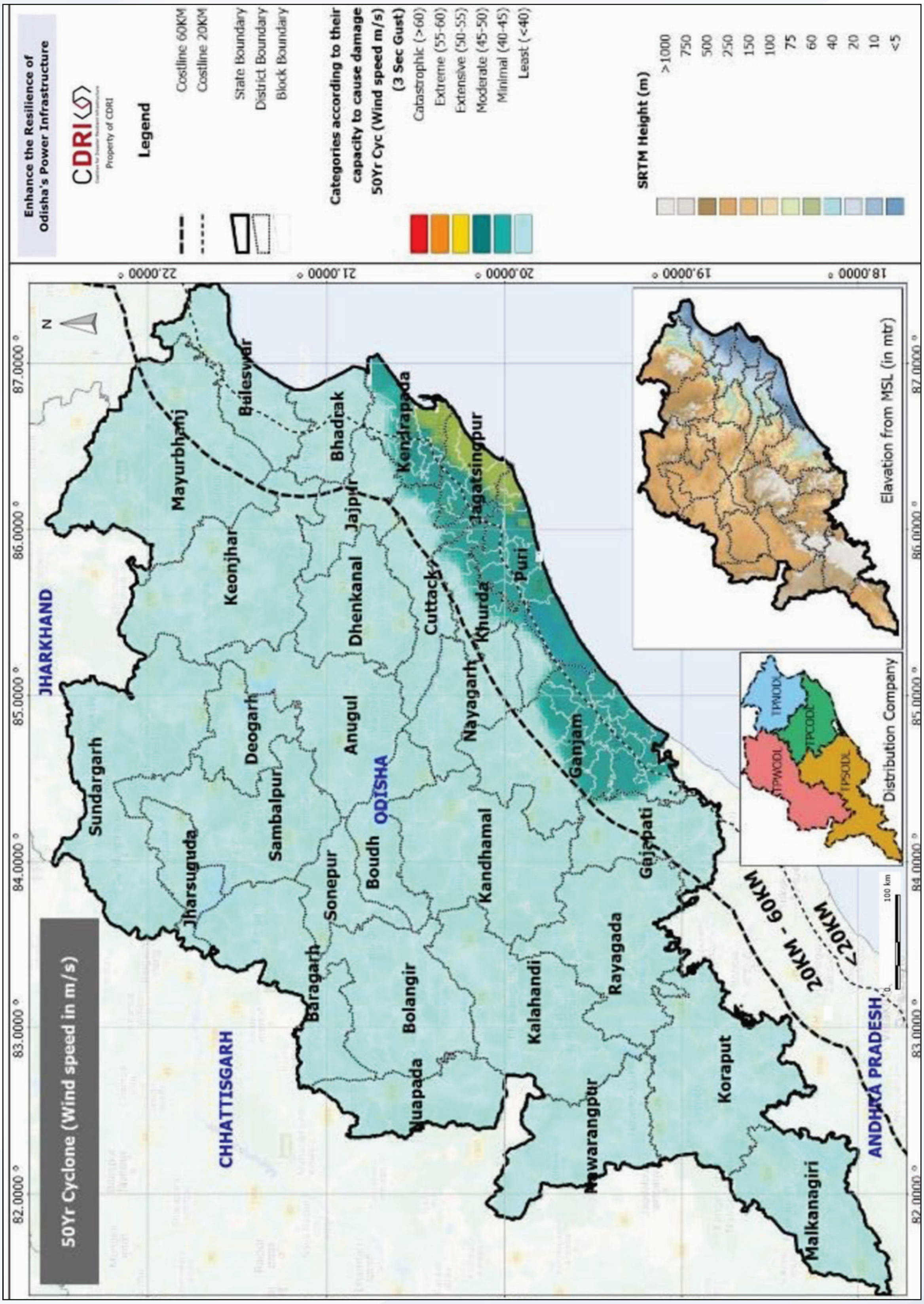


Figure A2: Cyclone zonation map (maximum sustain wind speed + climate change-50-year return period)

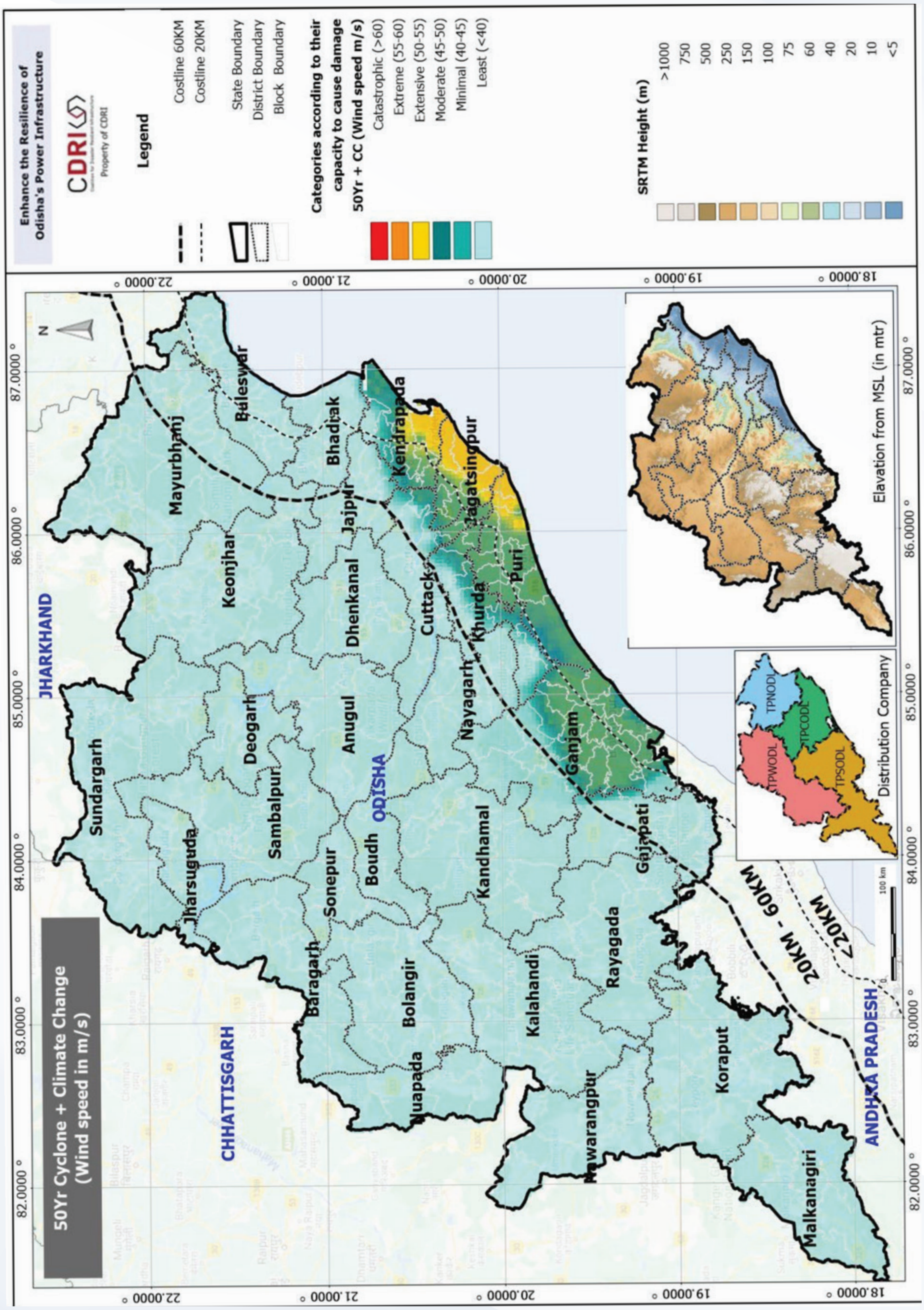


Figure A3: Cyclone zonation map (maximum sustain wind speed-100-year return period)

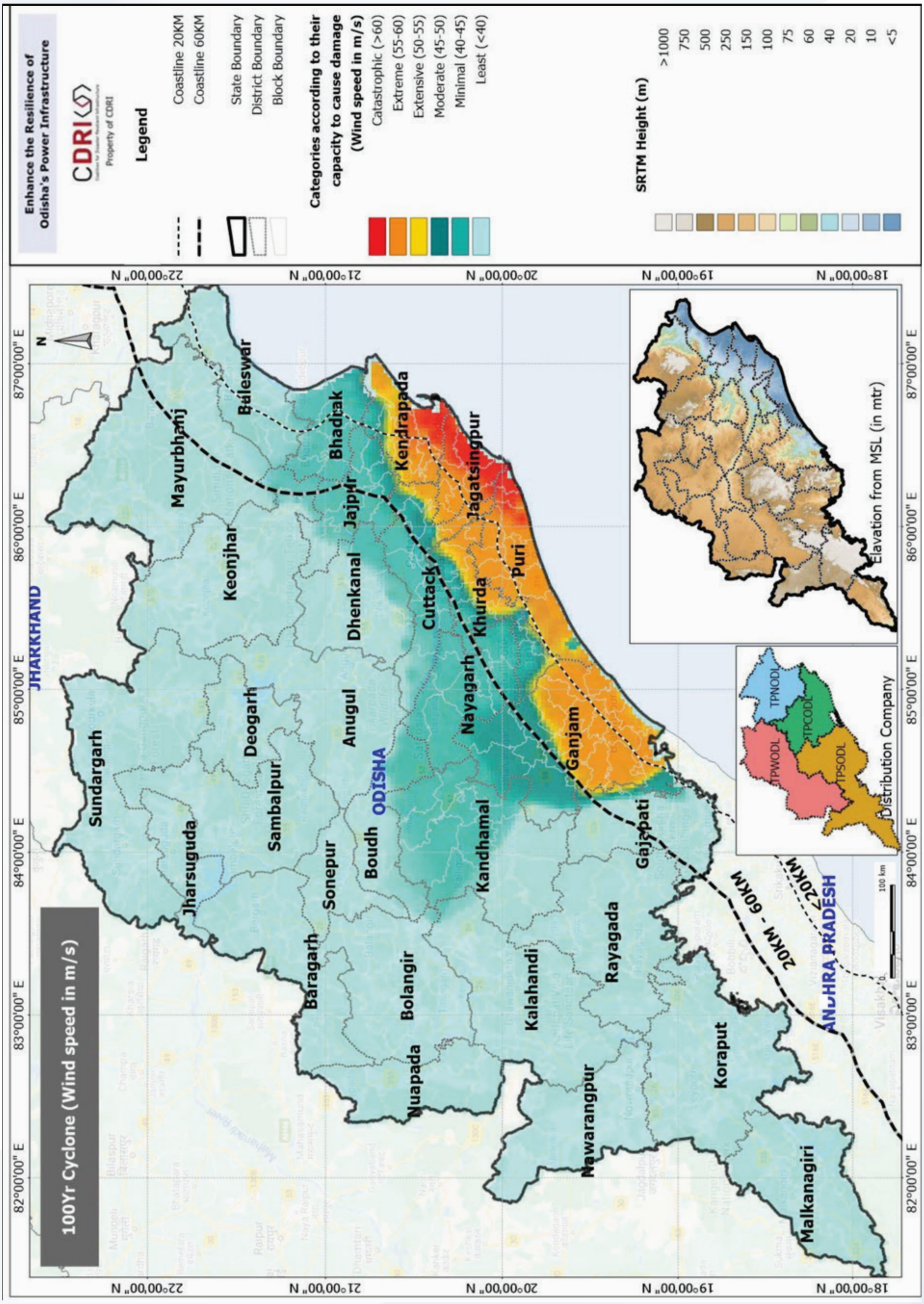
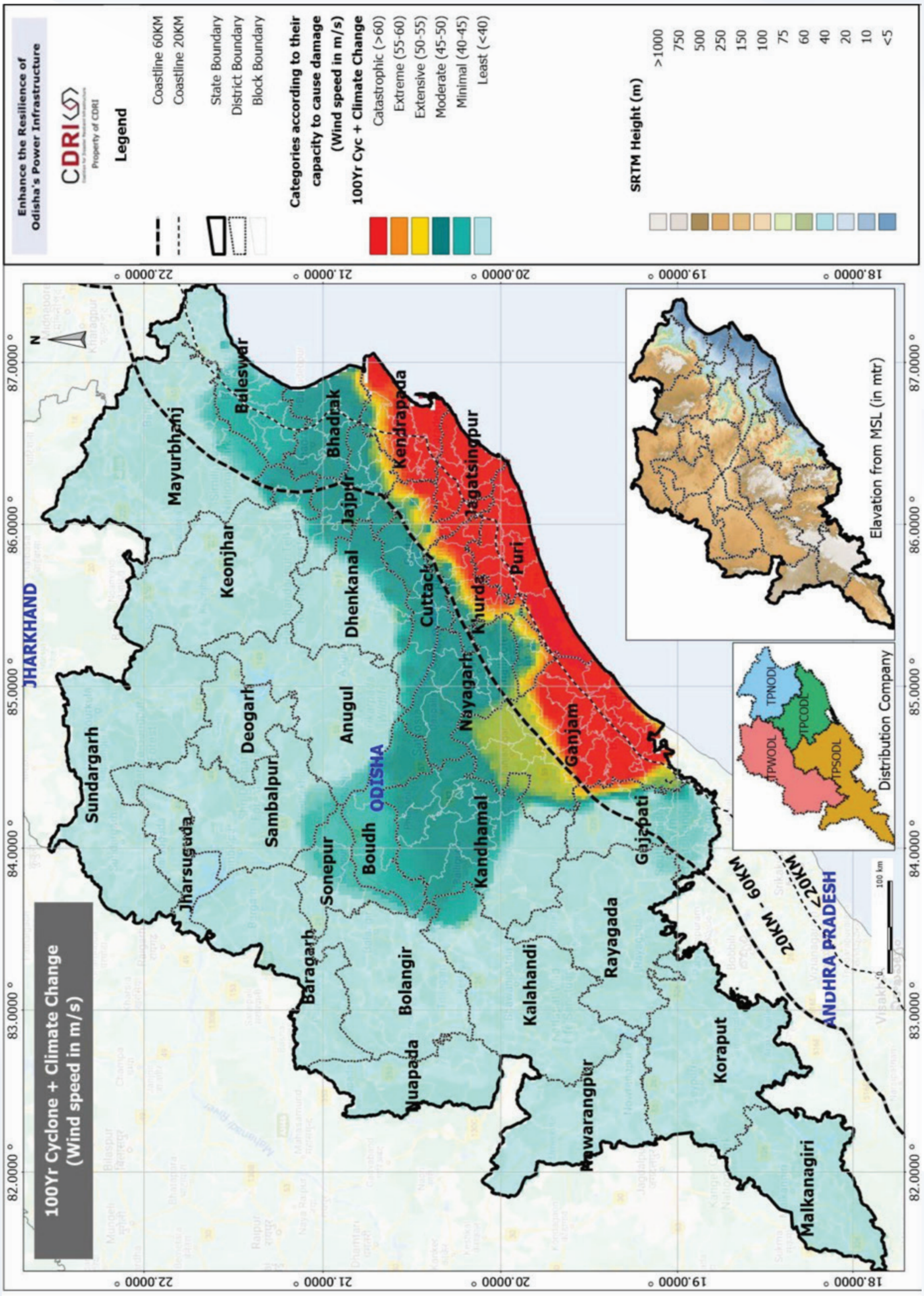
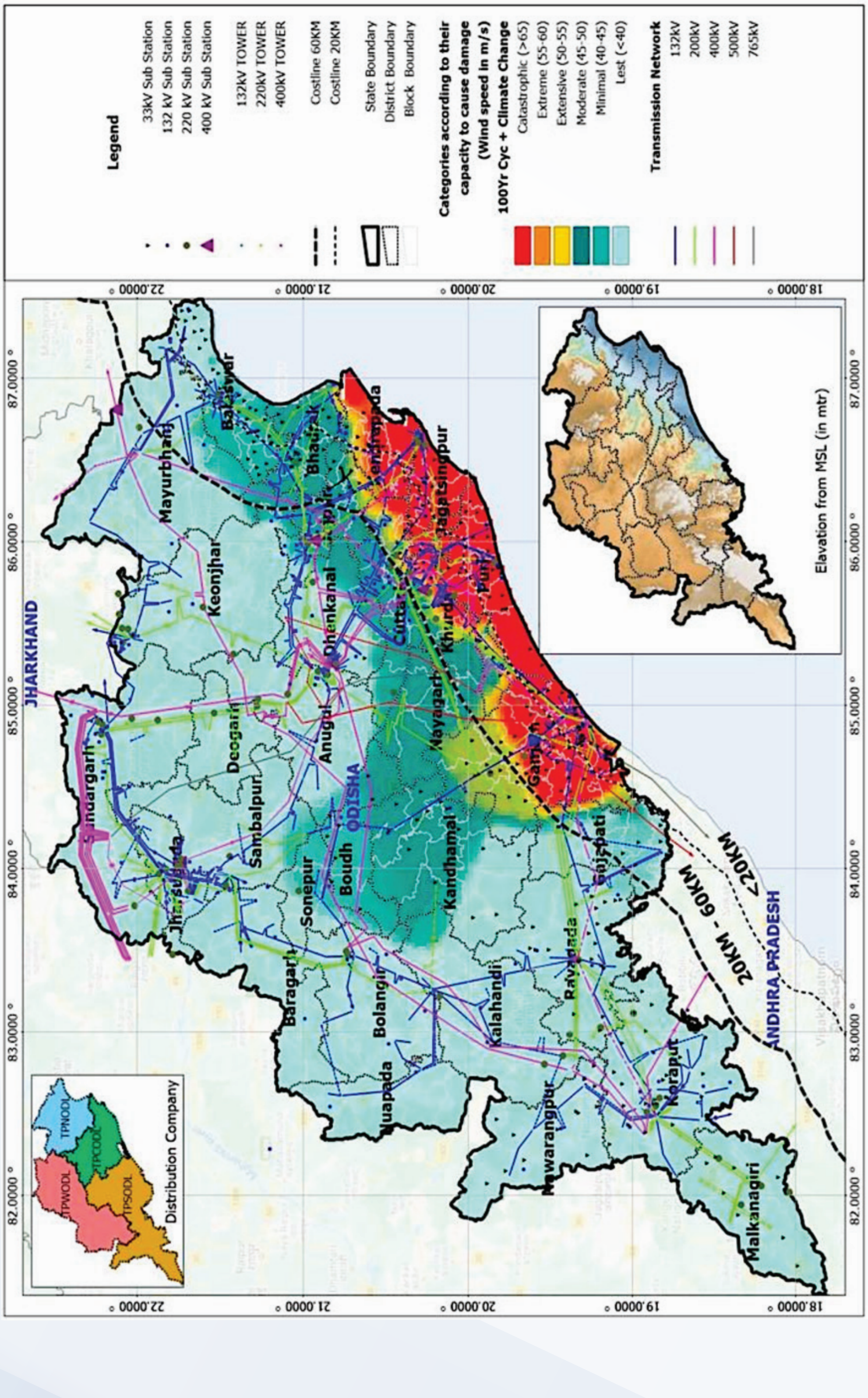


Figure A4: Cyclone zonation map (maximum sustain wind speed + climate change-100-year return period)



Exposure Map: Transmission and distribution networks in the 100-year return period (maximum sustained wind speed)-The zonation map for the 100-year return period shows exposure to transmission and distribution networks in the buffer zone of 20 km from the coastline and 20 to 60 km.

Figure A5: Cyclone exposure map of 100-year return period w.r.t transmission and distribution networks



Annexure 2: Flood Zonation Maps

Figure A6: Flood zonation map-1 in 25 years return period (Kendrapada district)

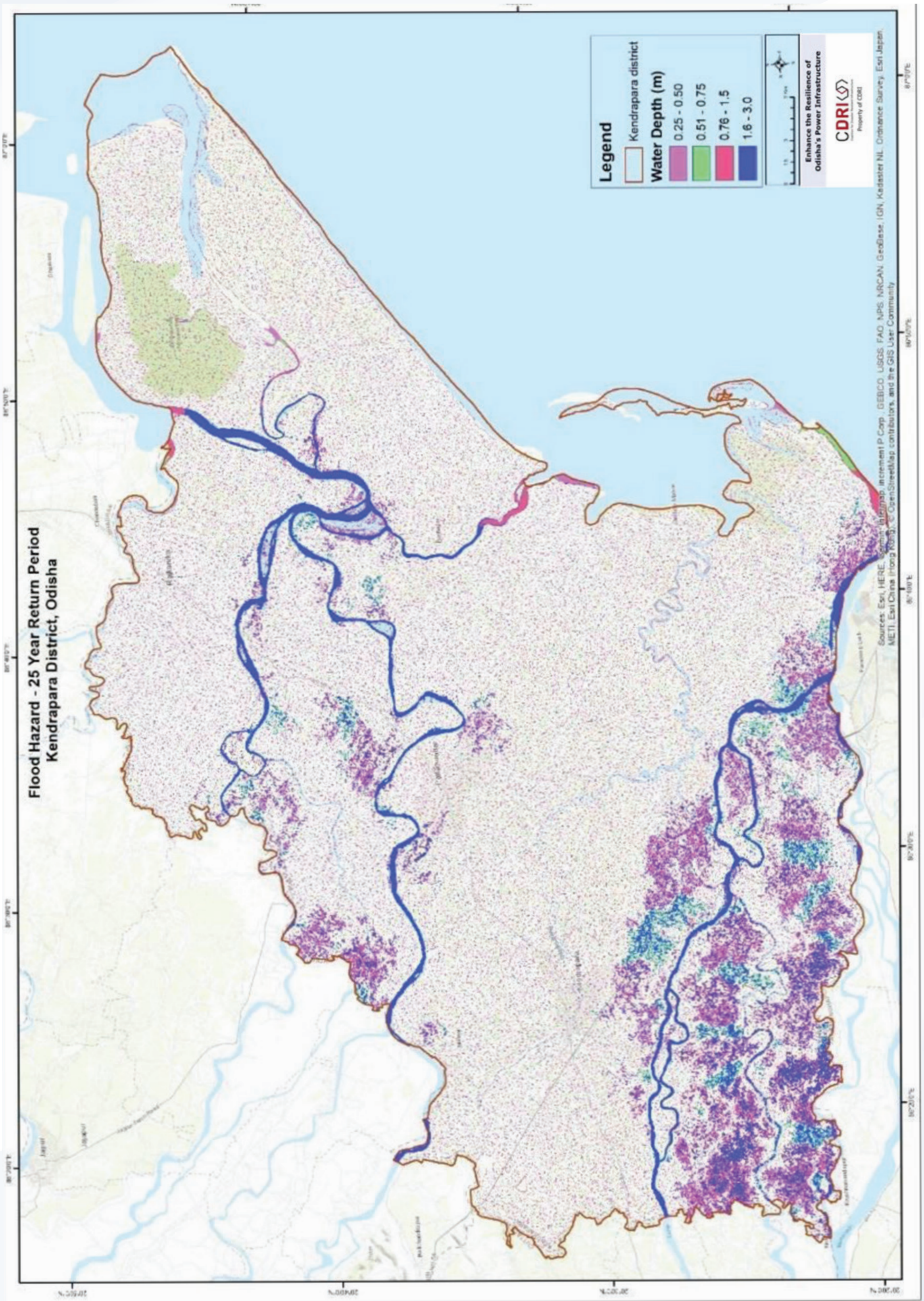


Figure A7: Flood zonation map-1 in 50 years return period (Kendrapada district)

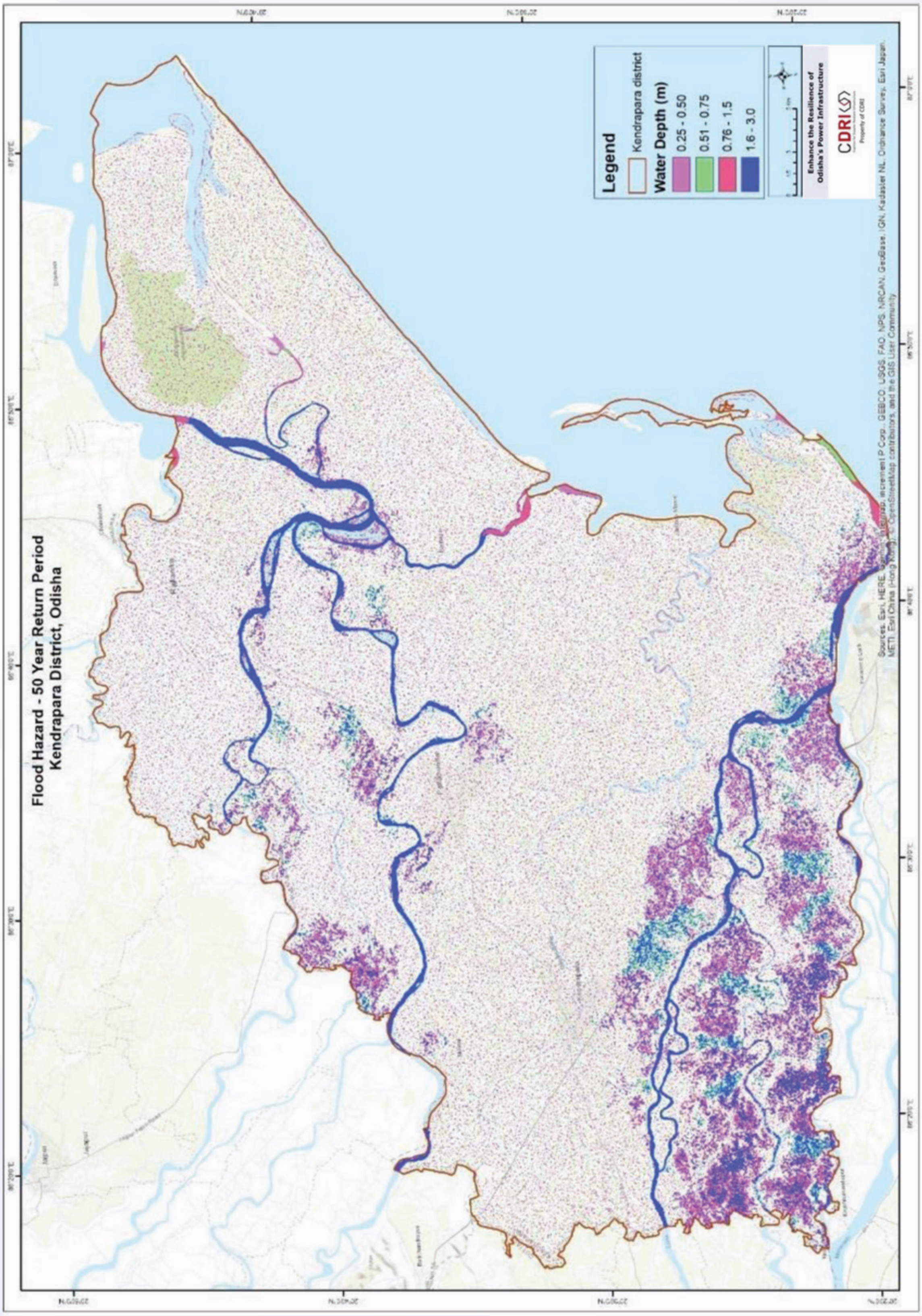


Figure A8: Flood zonation map-future scenario (1 in 5 years return period in Kendrapada district)

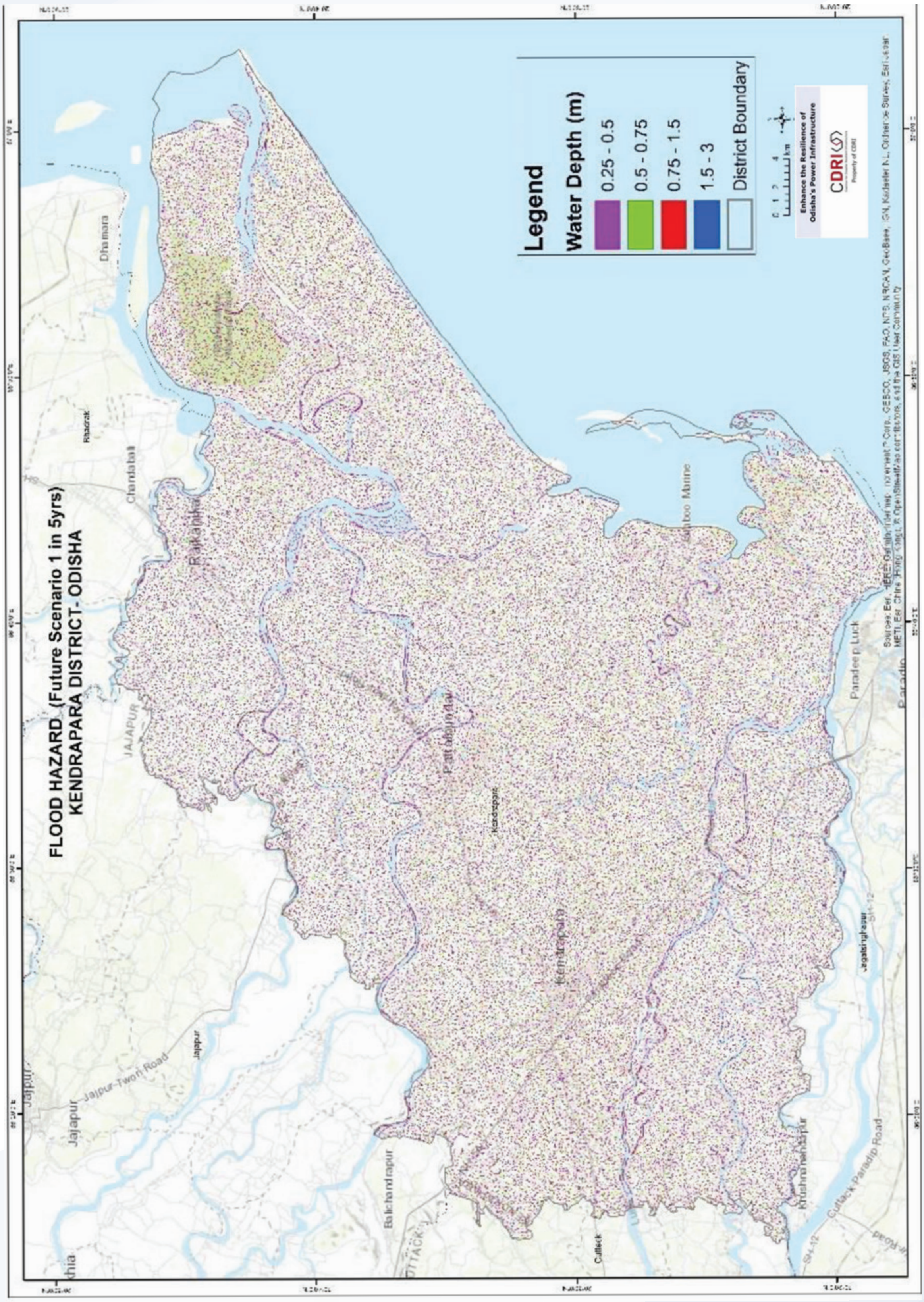


Figure A9: Flood zonation map-future scenario (1 in 100 years return period in Kendrapada district)

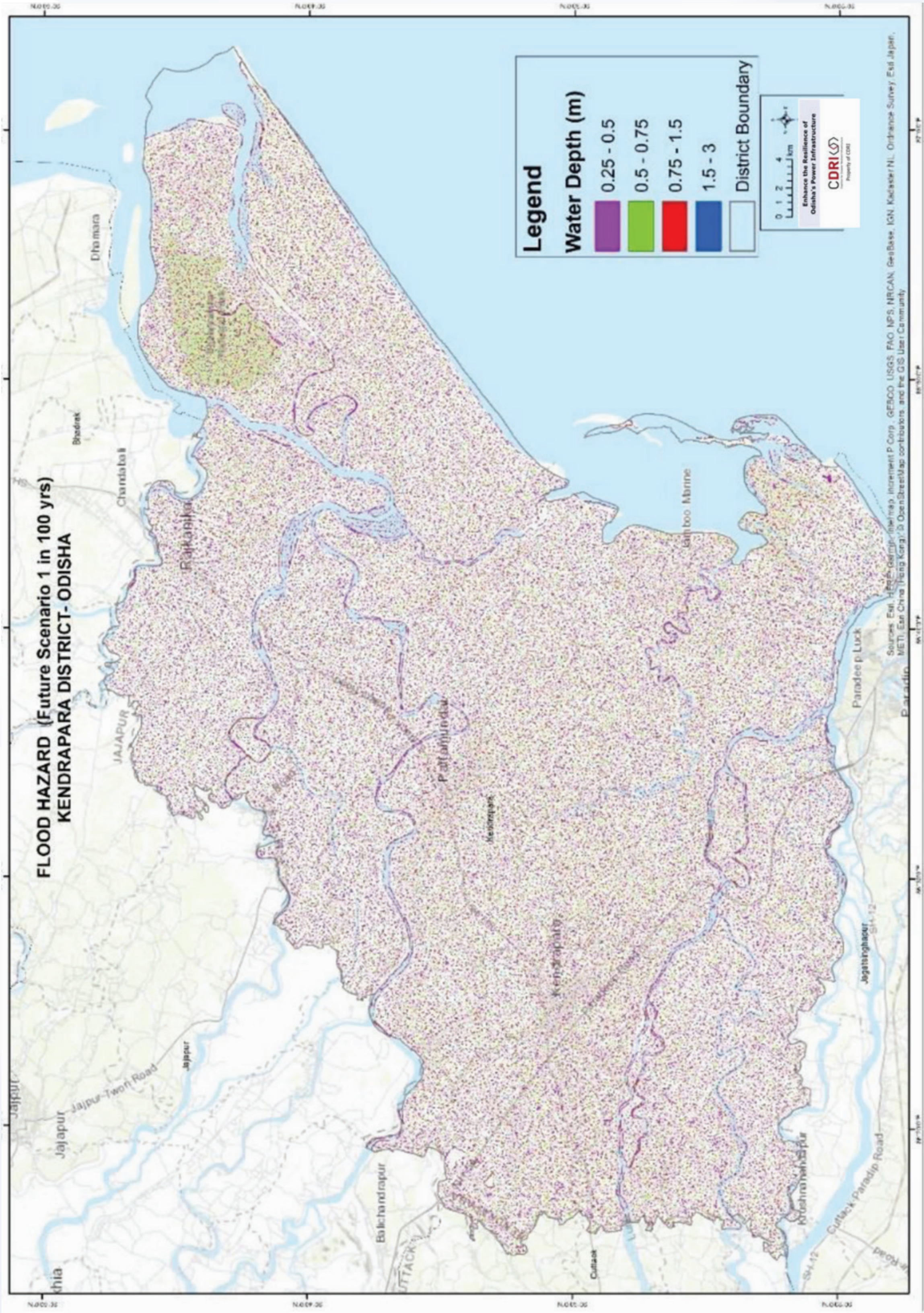


Figure A10: Flood zonation map 1 in 5 years return period (Jagatsinghpur district)

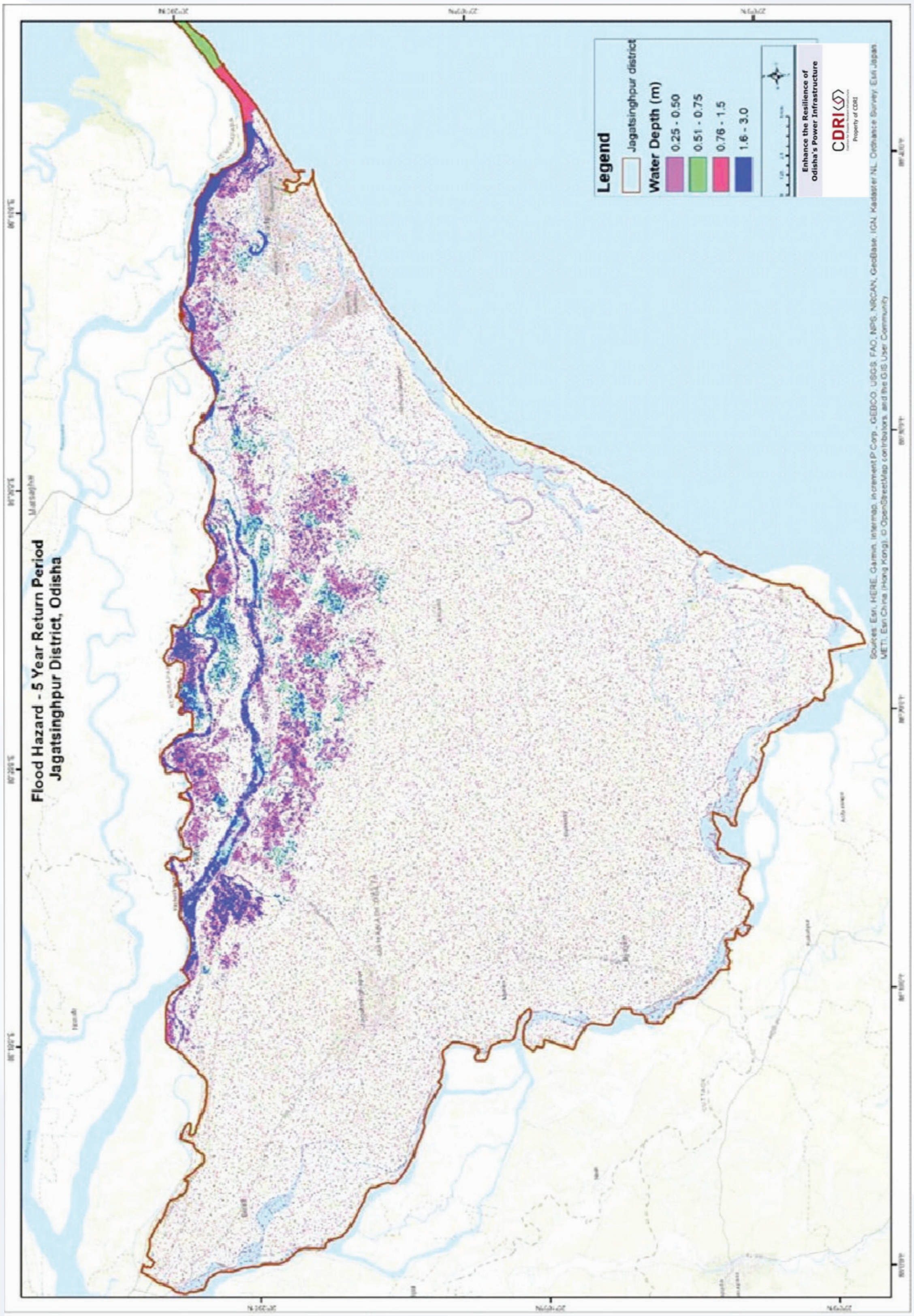


Figure A11: Flood zonation map-1 in 25 years return period (Jagatsinghpur district)

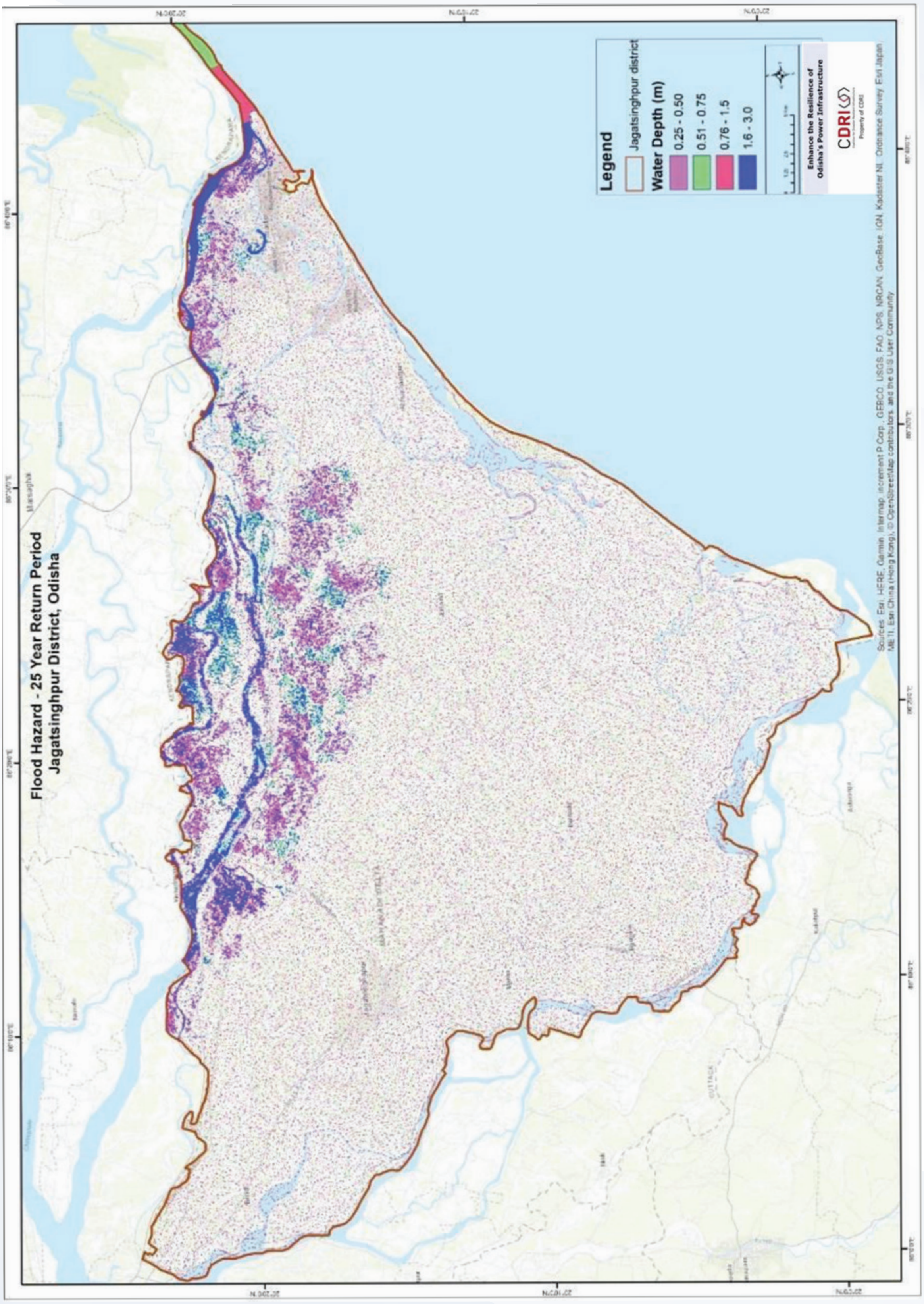


Figure A12: Flood zonation map-1 in 50 years return period (Jagatsinghpur district)

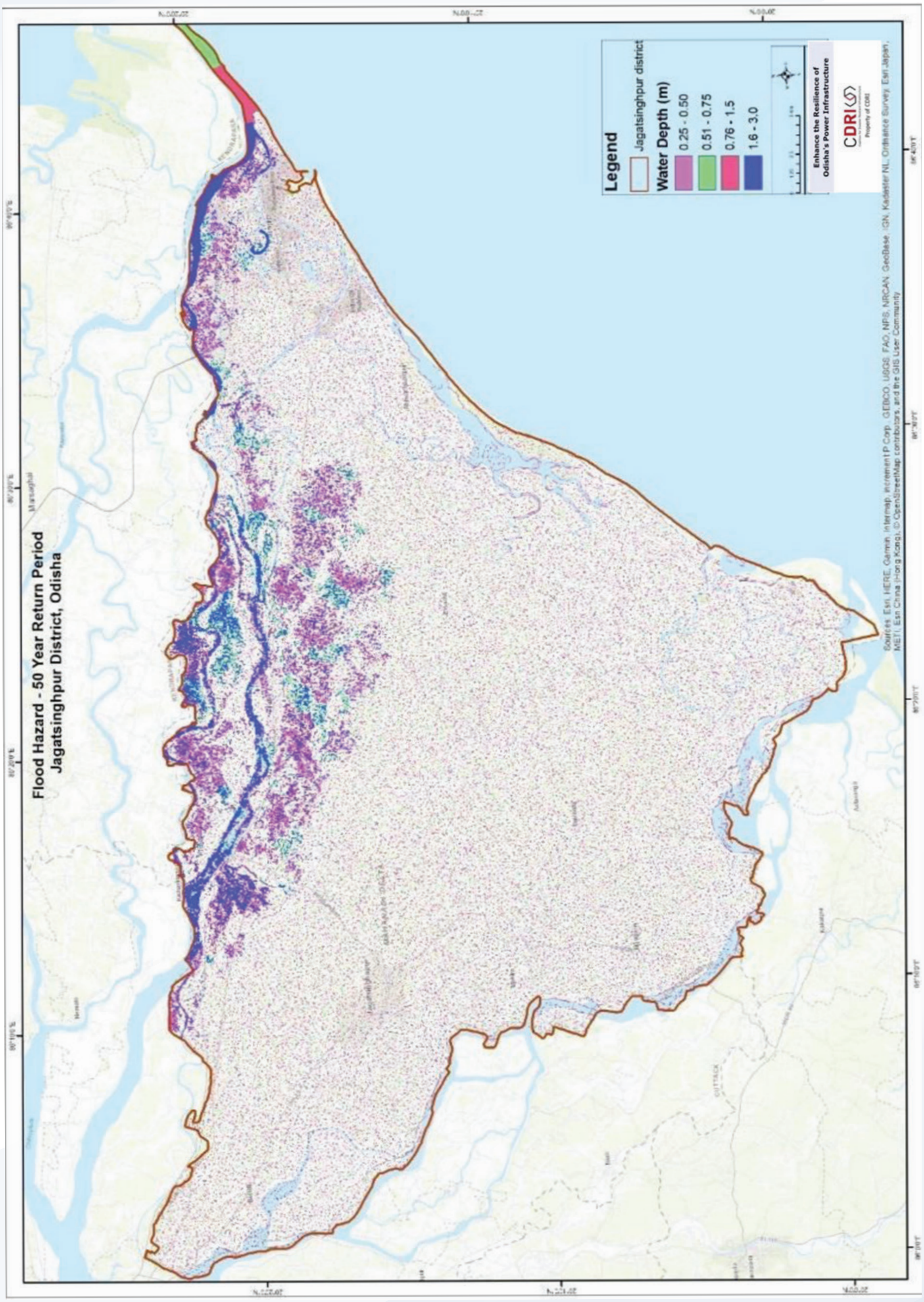


Figure A13: Flood zonation map-1 in 100 years return period (Jagatsinghpur district)

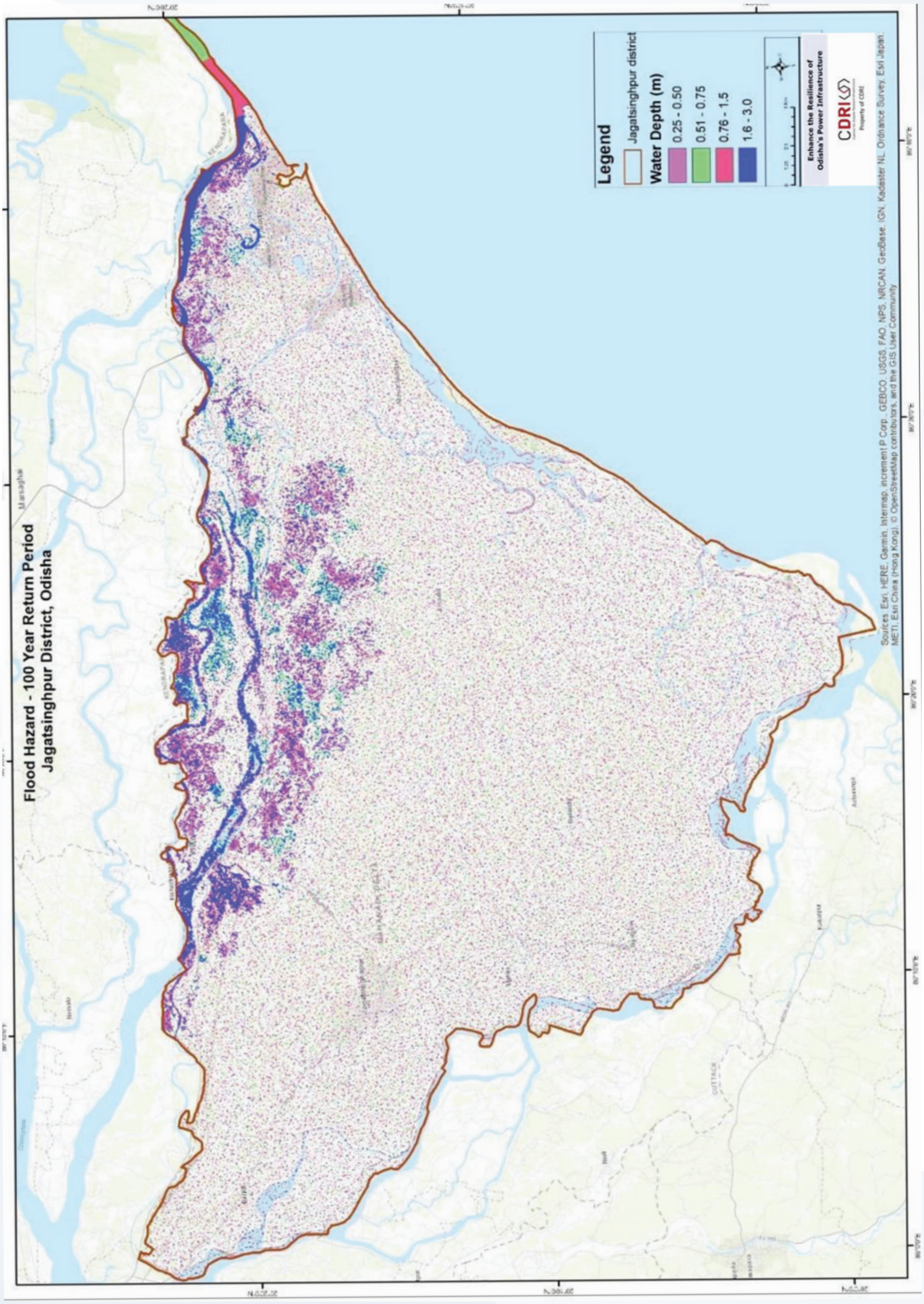


Figure A14: Flood zonation map-future scenario (1 in 5 years return period in Jagatsinghpur district)

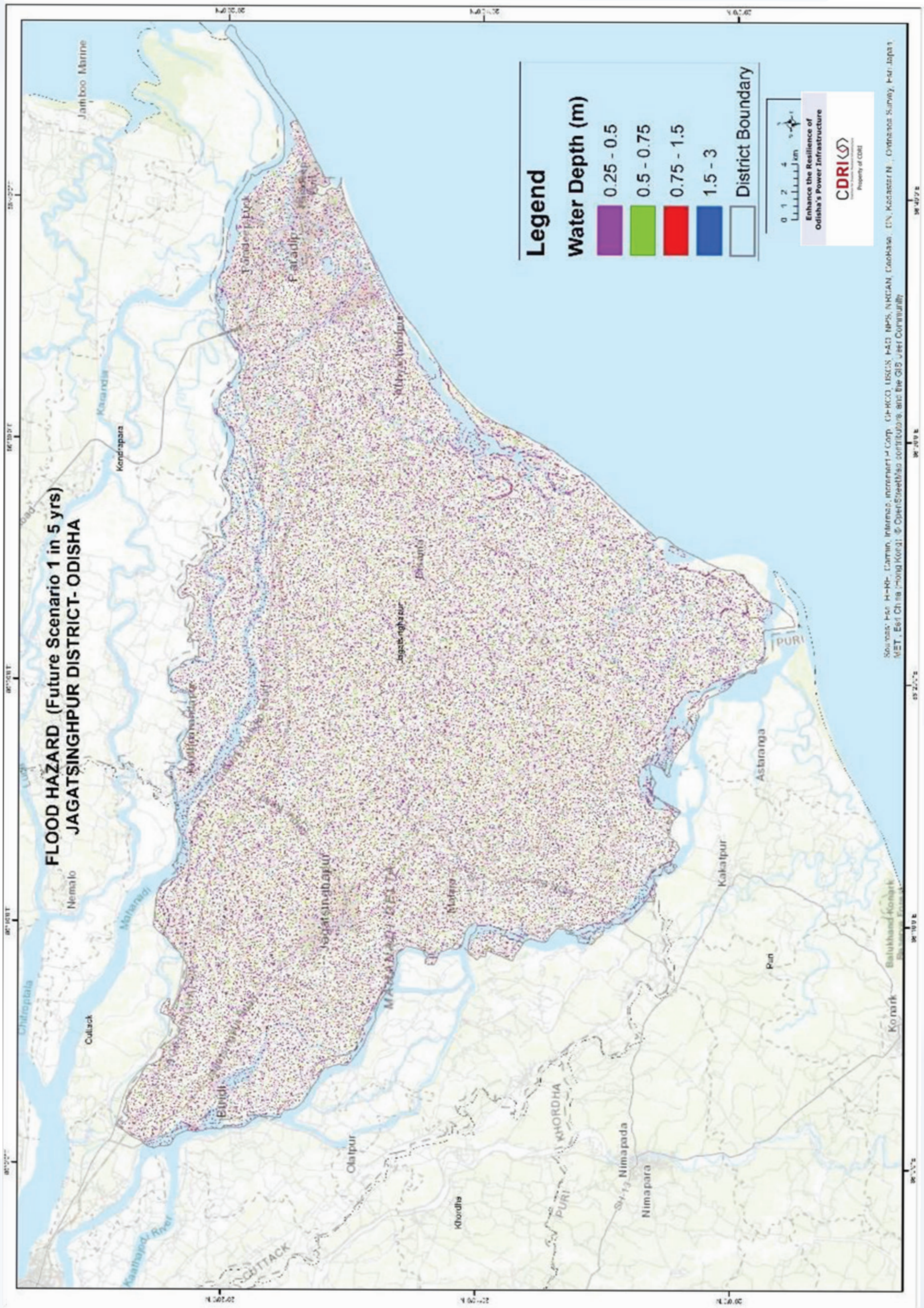


Figure A15: Flood zonation map-future scenario (1 in 100 years return period in Jagatsinghpur district)

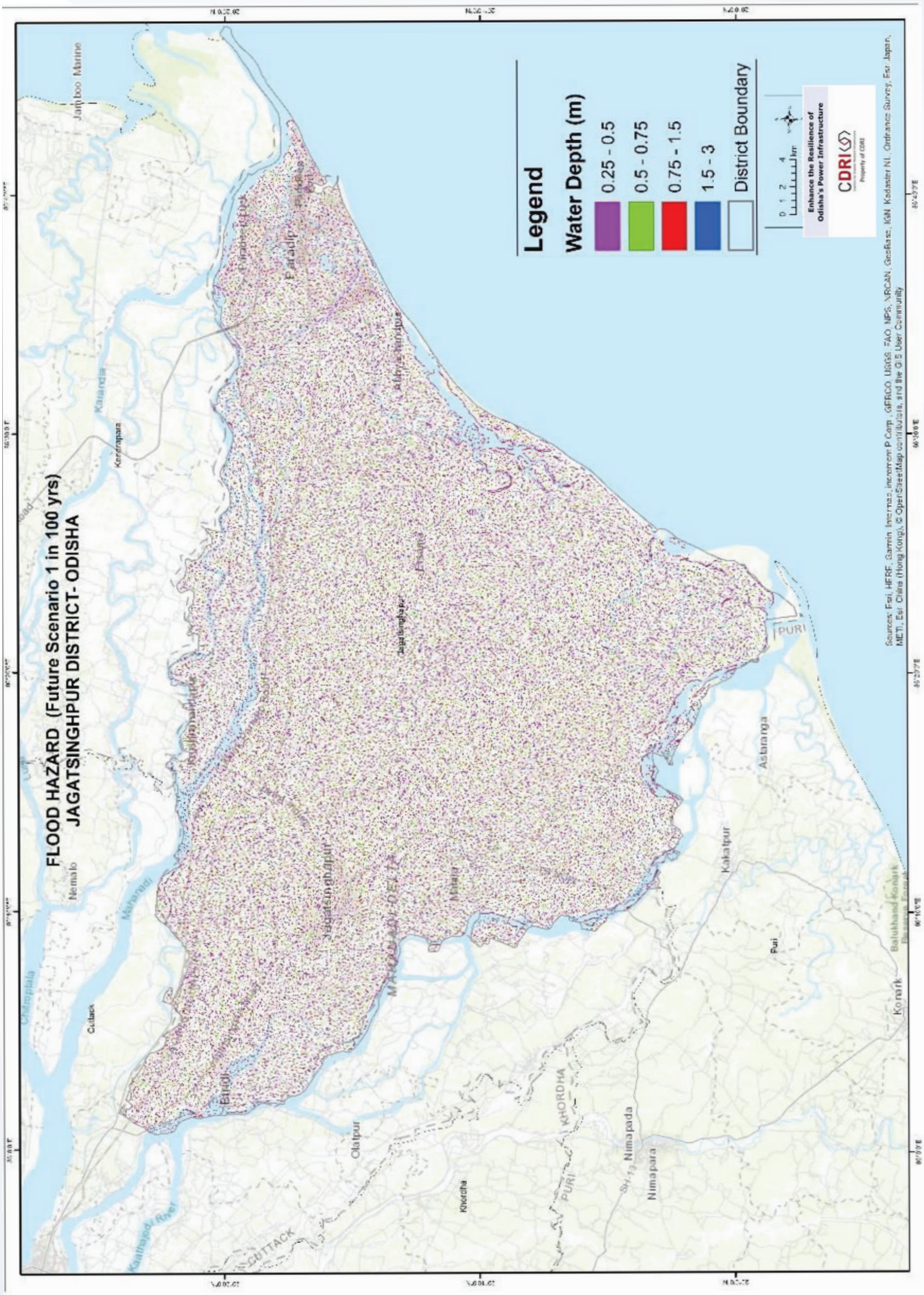


Figure A16: Flood zonation map-1 in 5 years return period (Bhadrak district)

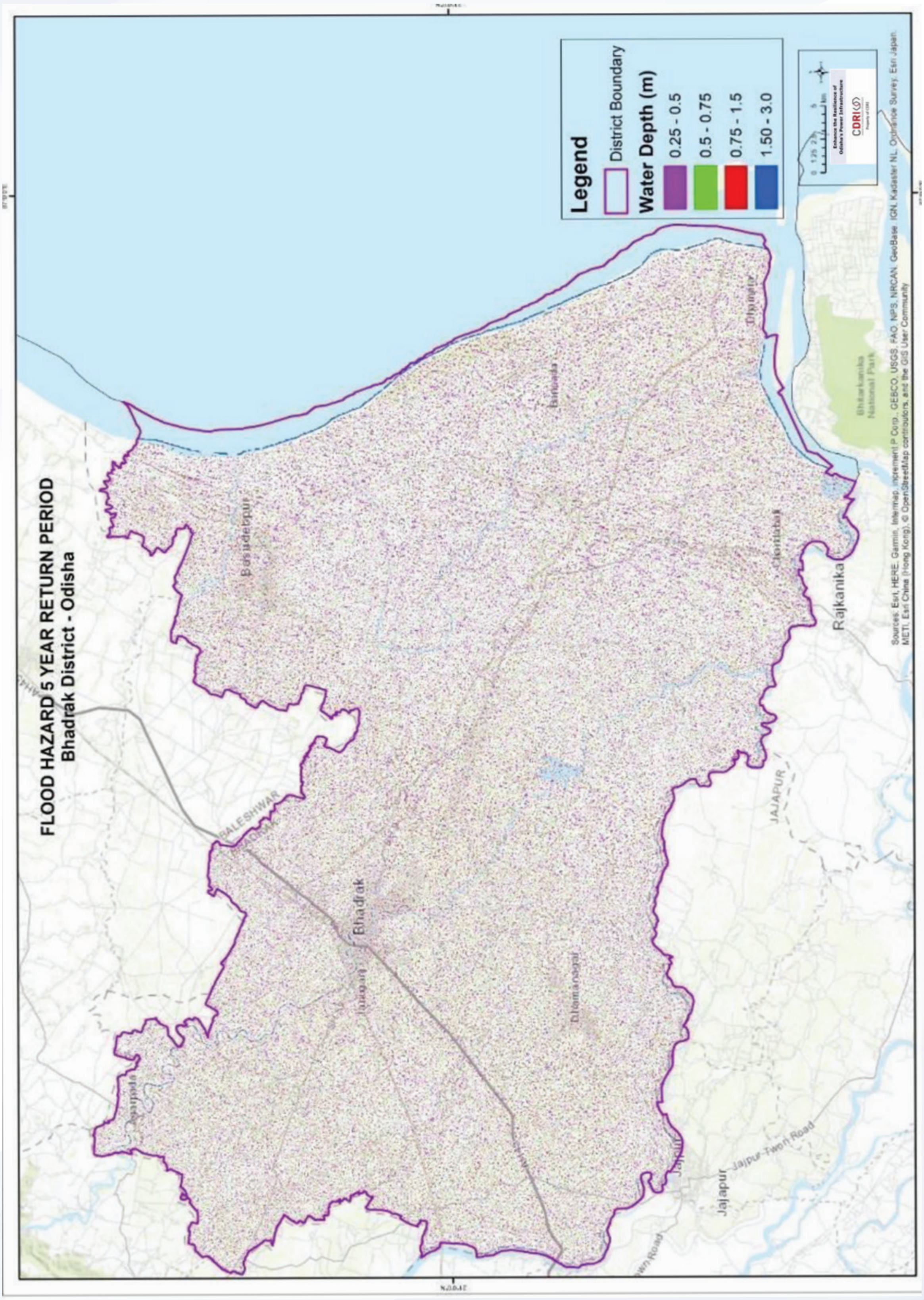


Figure A17: Flood zonation map-1 in 25 years return period (Bhadrak district)

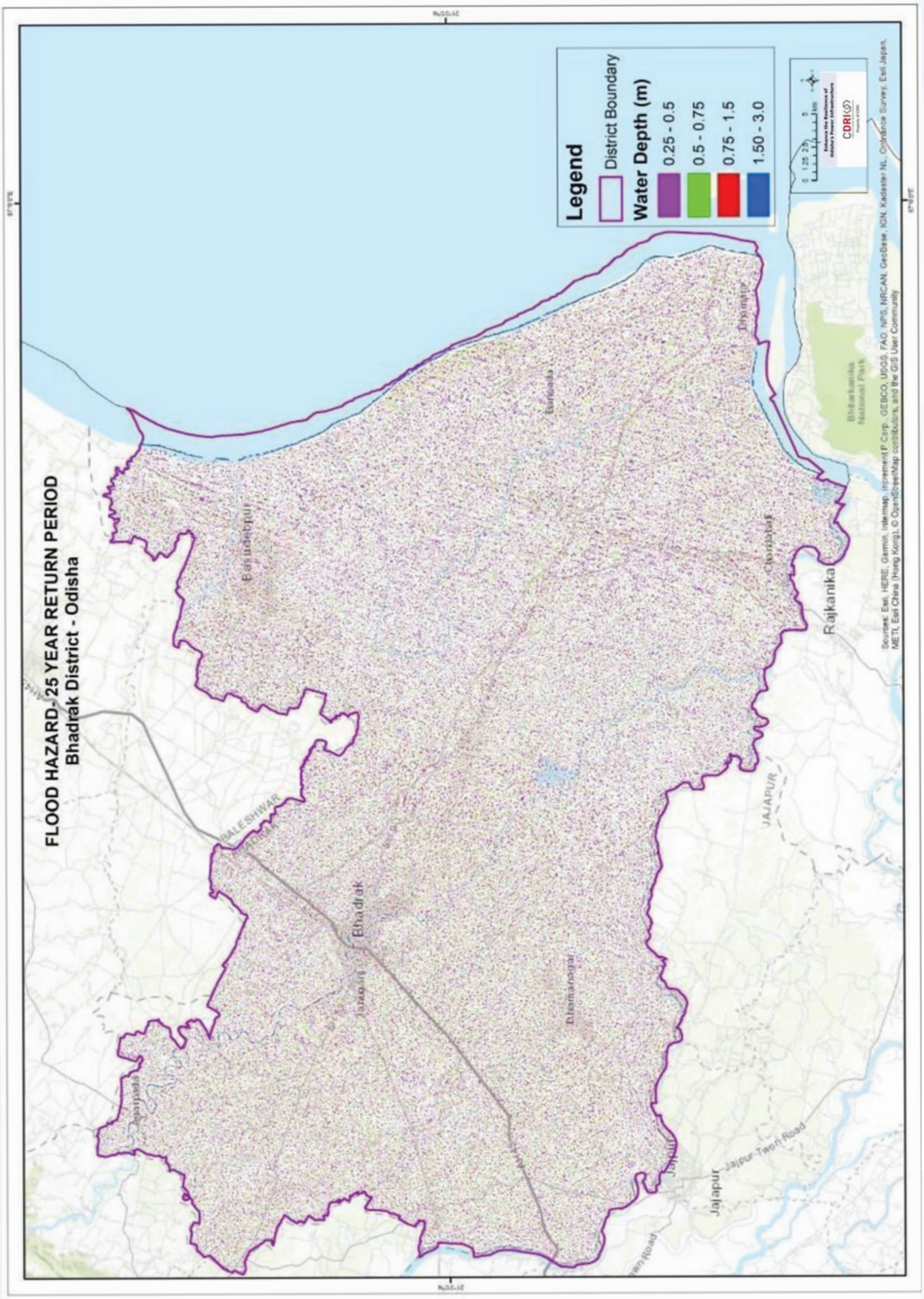


Figure A18: Flood zonation map-1 in 50 years return period (Bhadrak district)

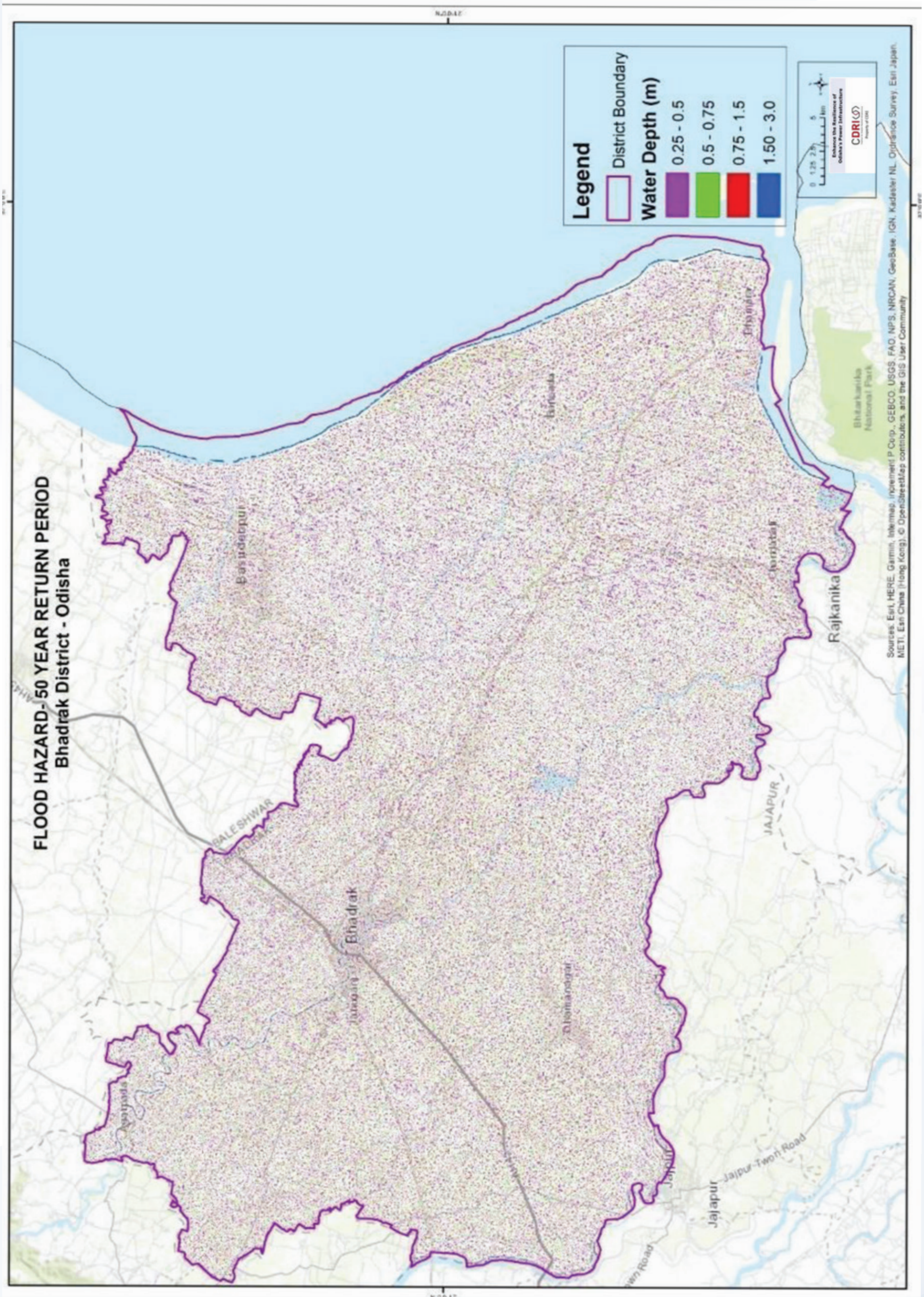


Figure A19: Flood zonation map-1 in 100 years return period (Bhadrak district)

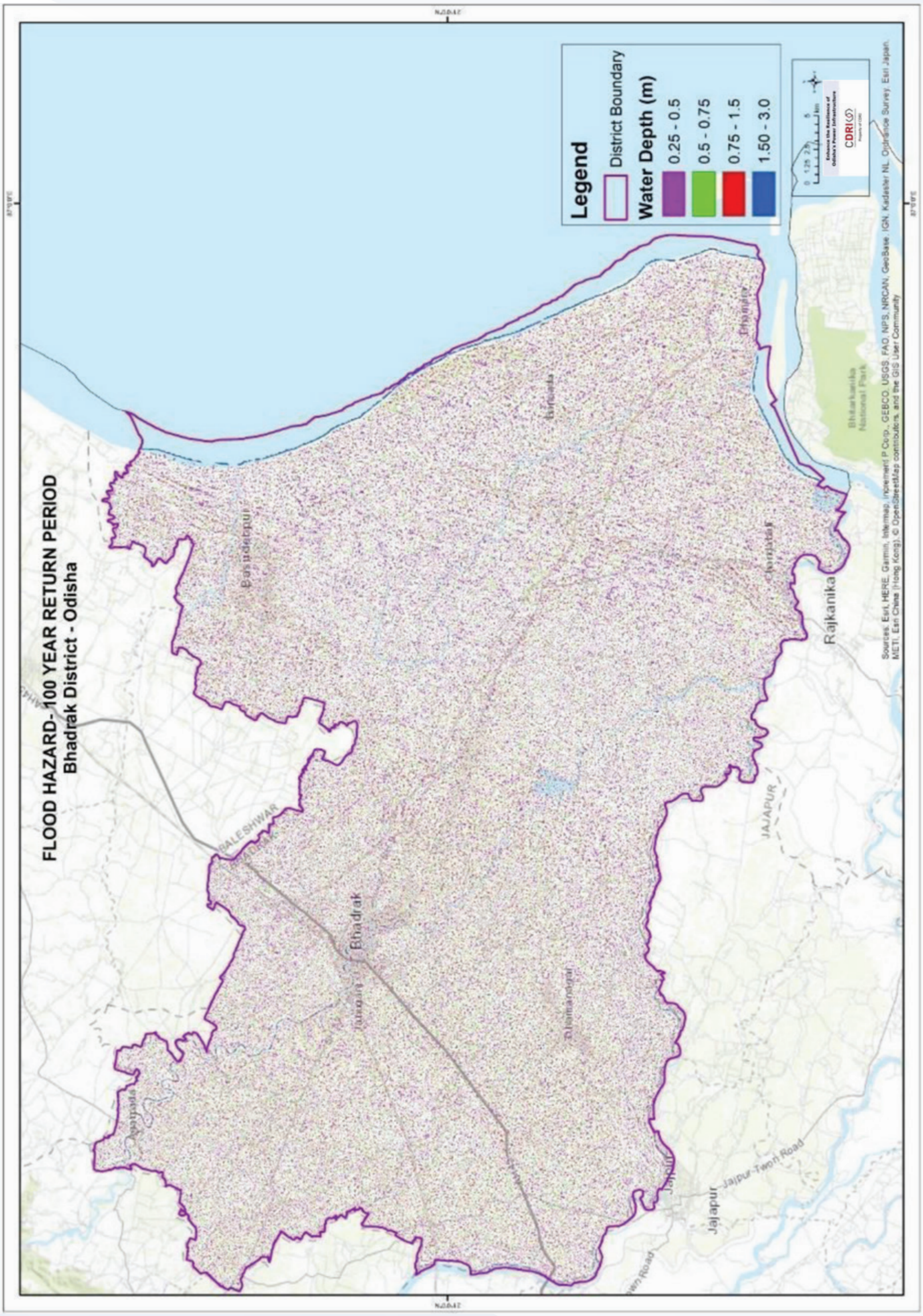


Figure A20: Flood zonation map-future scenario (1 in 5 years return period in Bhadrak district)

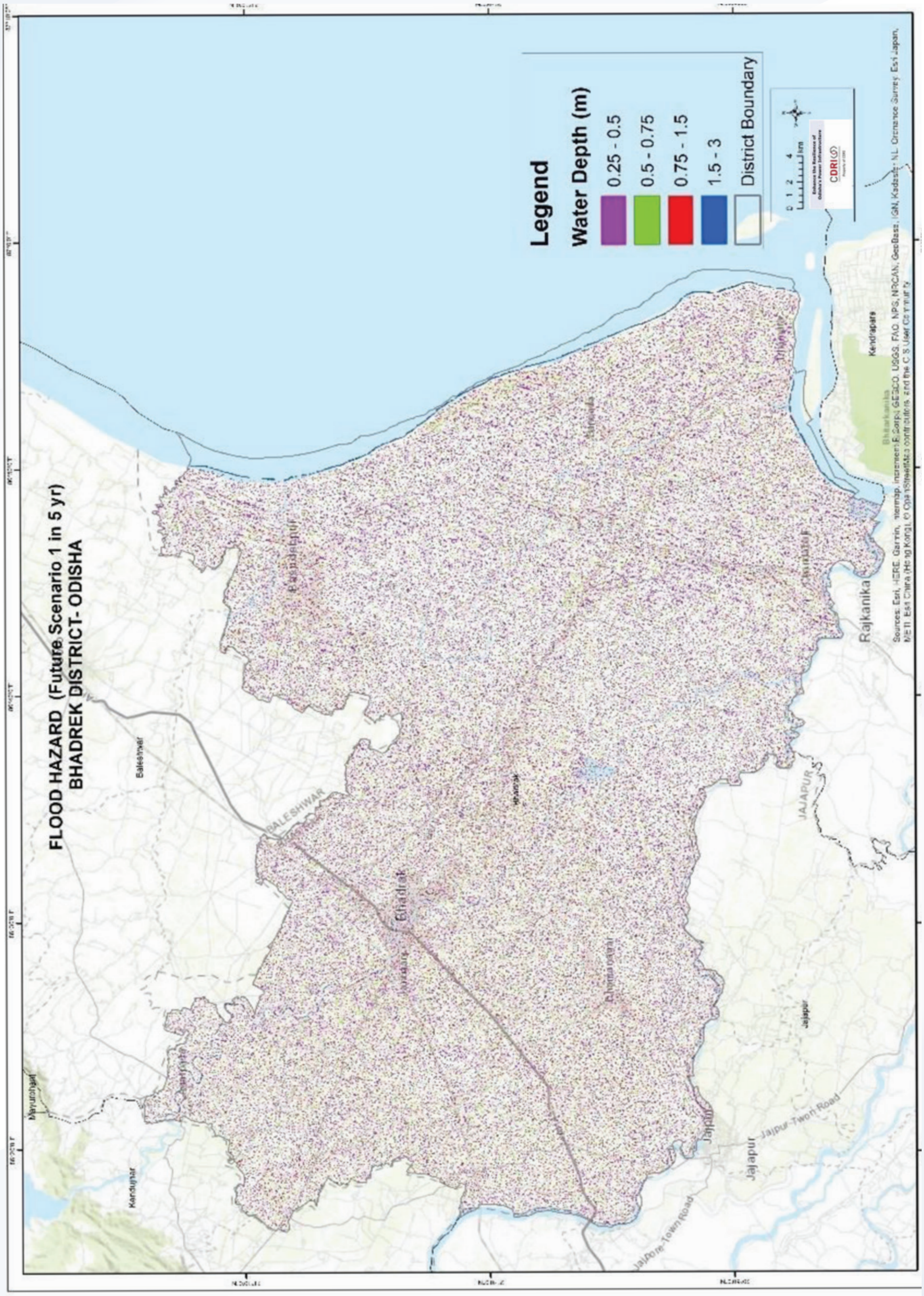


Figure A21: Flood zonation map-future scenario (1 in 100 years return period in Bhadrak district)

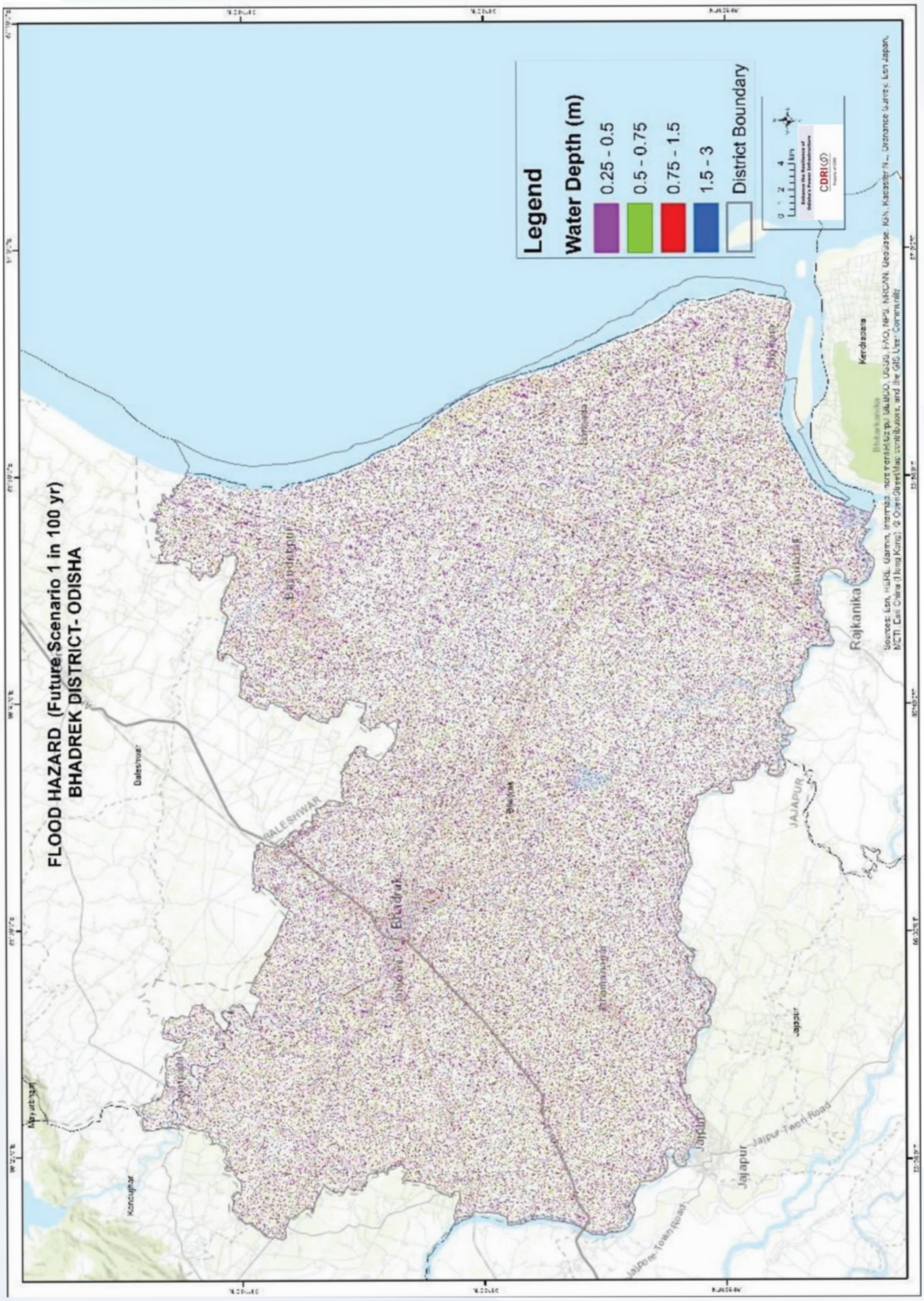


Figure A22: Flood zonation map-1 in 5 years return period (Balasore district)

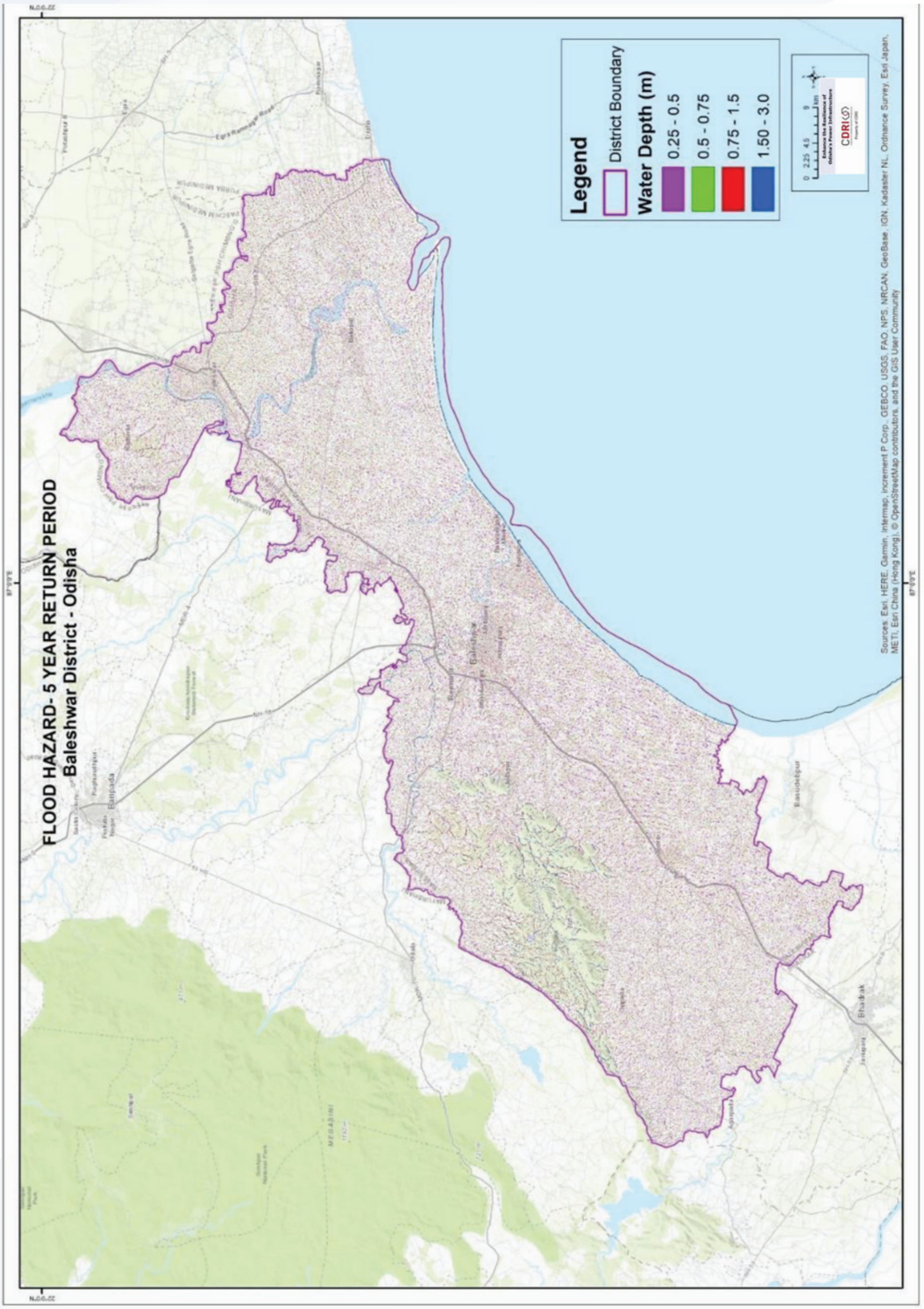


Figure A23: Flood zonation map-1 in 25 years return period (Balasore district)

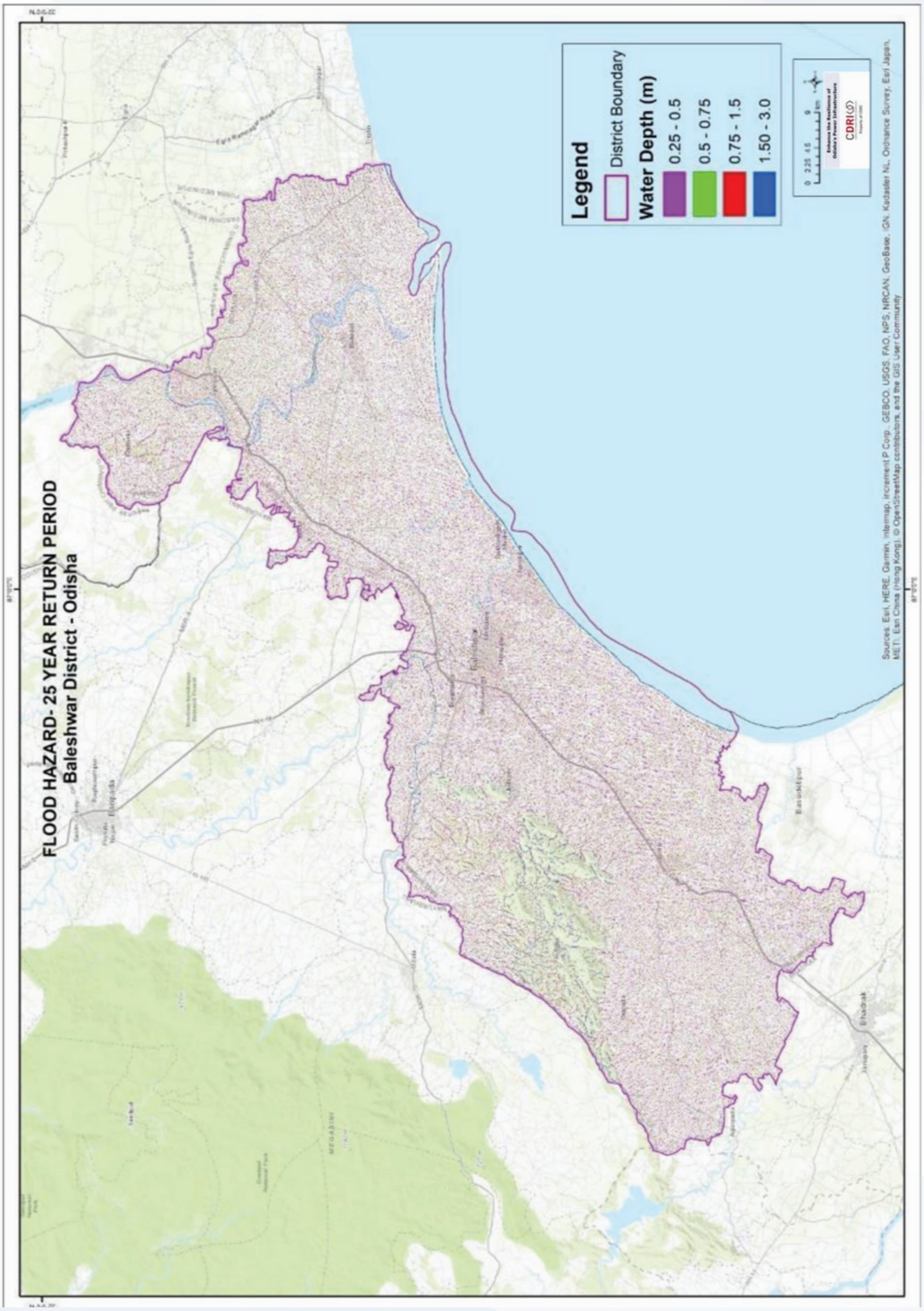


Figure A24: Flood zonation map-1 in 50 years return period (Balasore district)

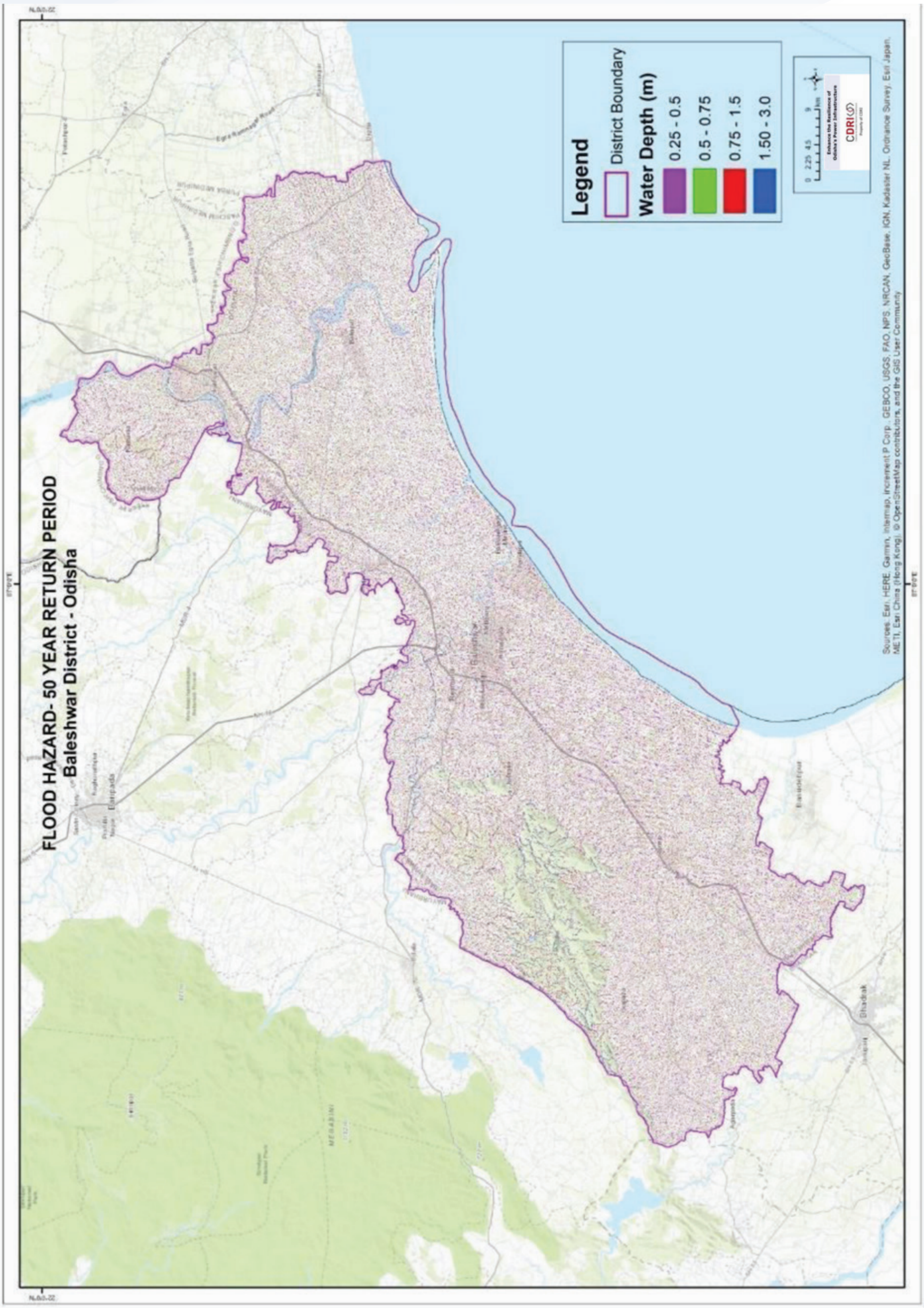


Figure A25: Flood zonation map-1 in 100 years return period (Balasore district)

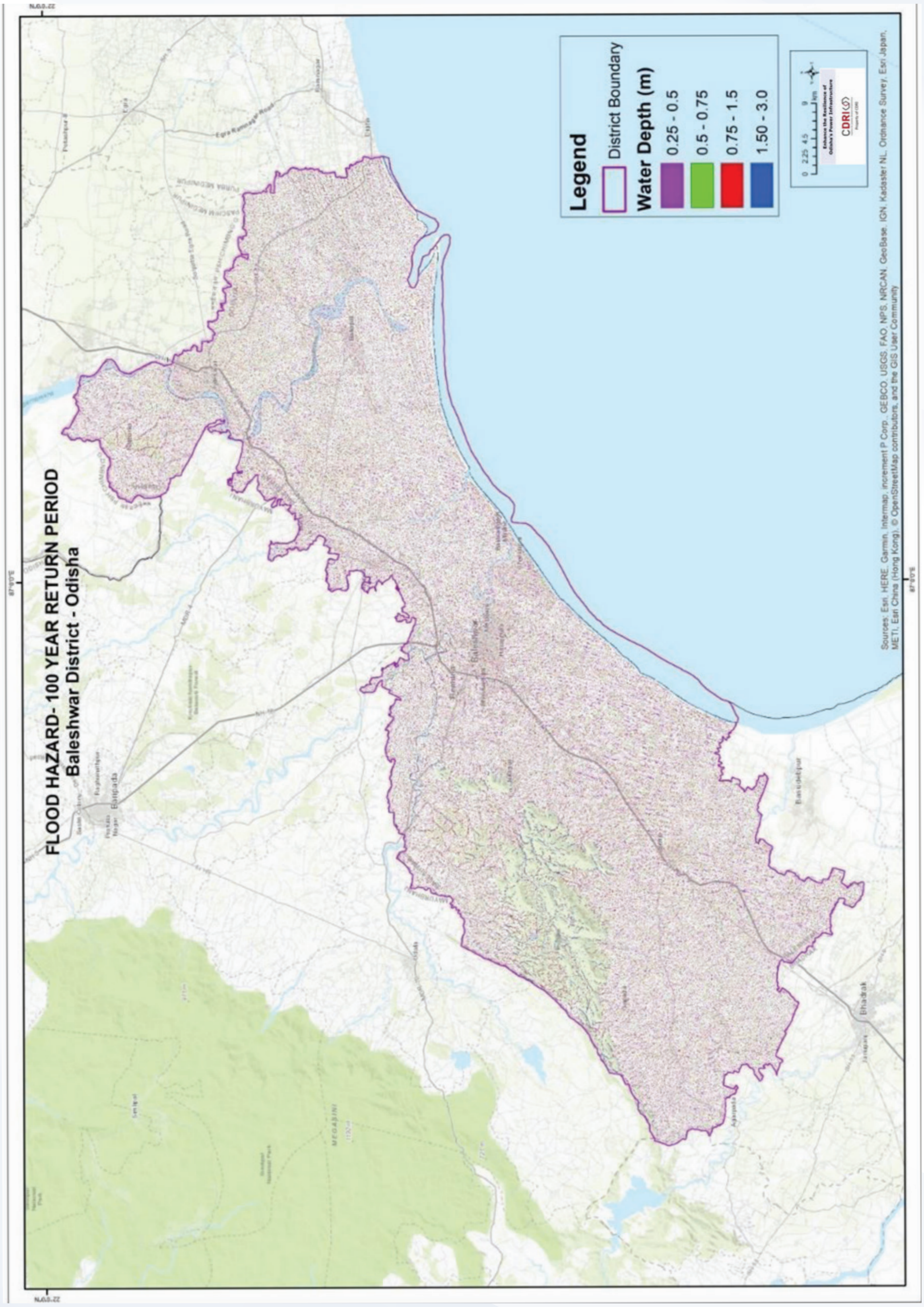


Figure A26: Flood zonation map-future scenario (1 in 5 years return period in Balasore district)

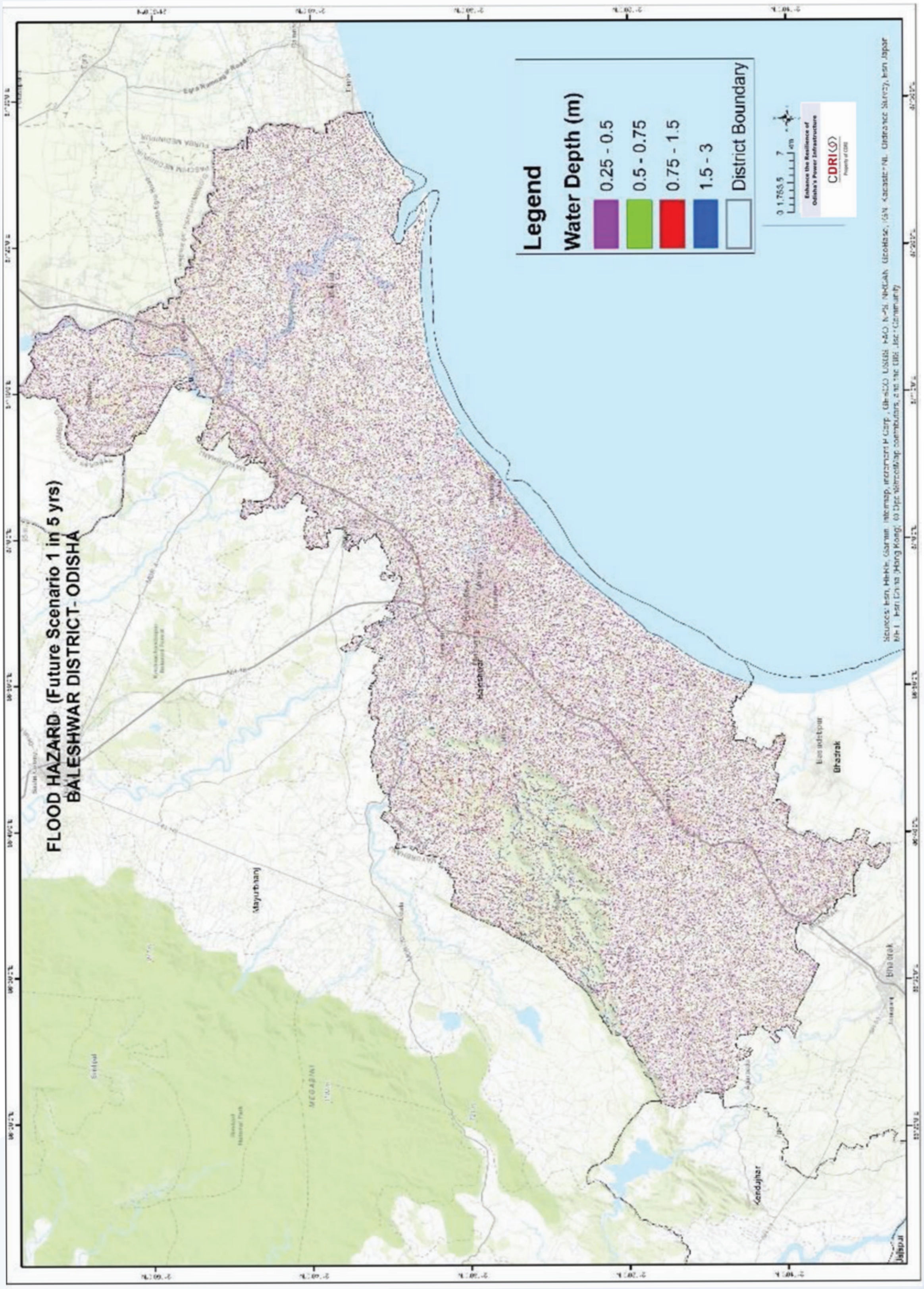


Figure A27: Flood zonation map-future scenario (1 in 100 years return period in Balasore district)

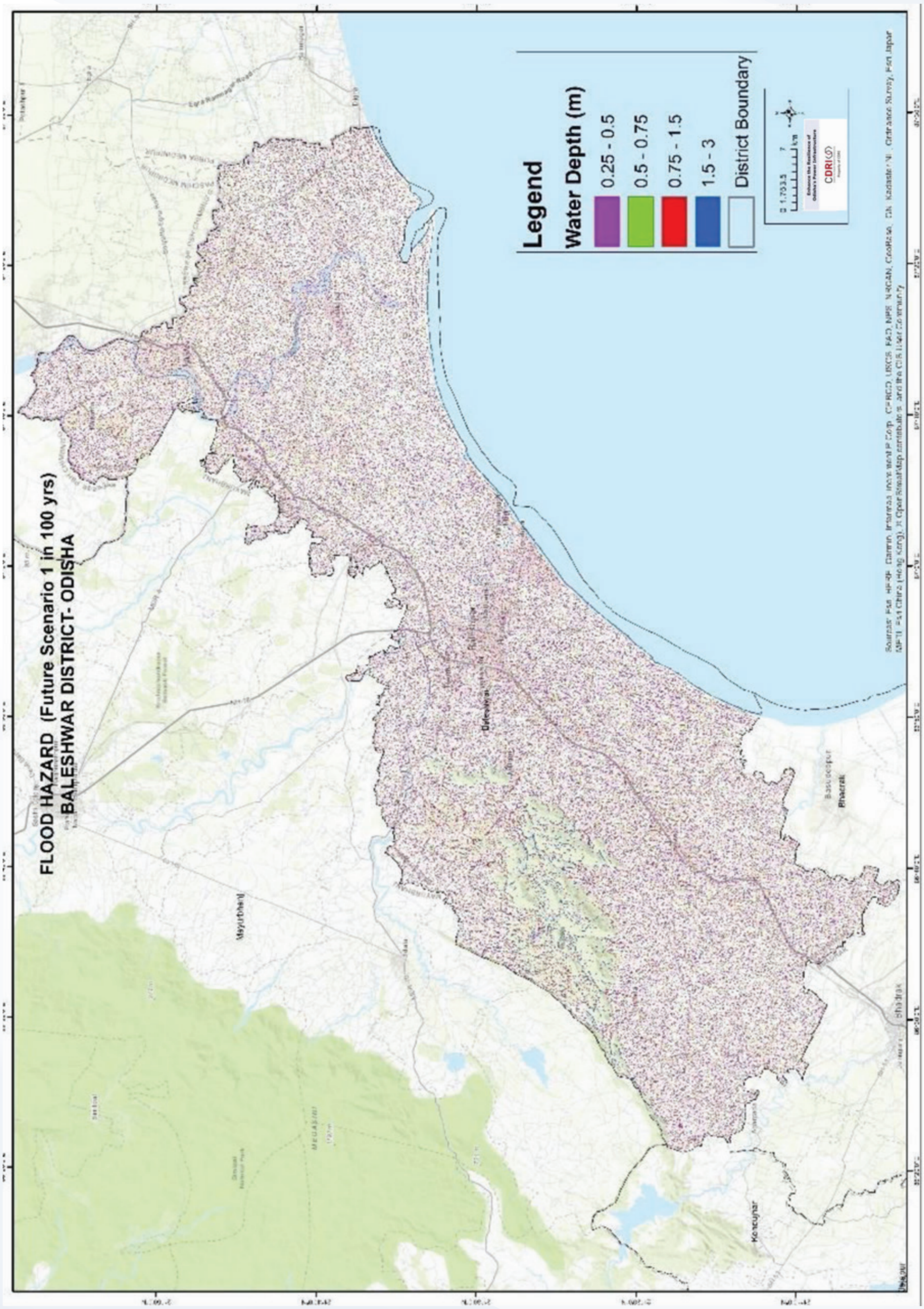


Figure A28: Flood zonation map-1 in 5 years return period (Puri city)

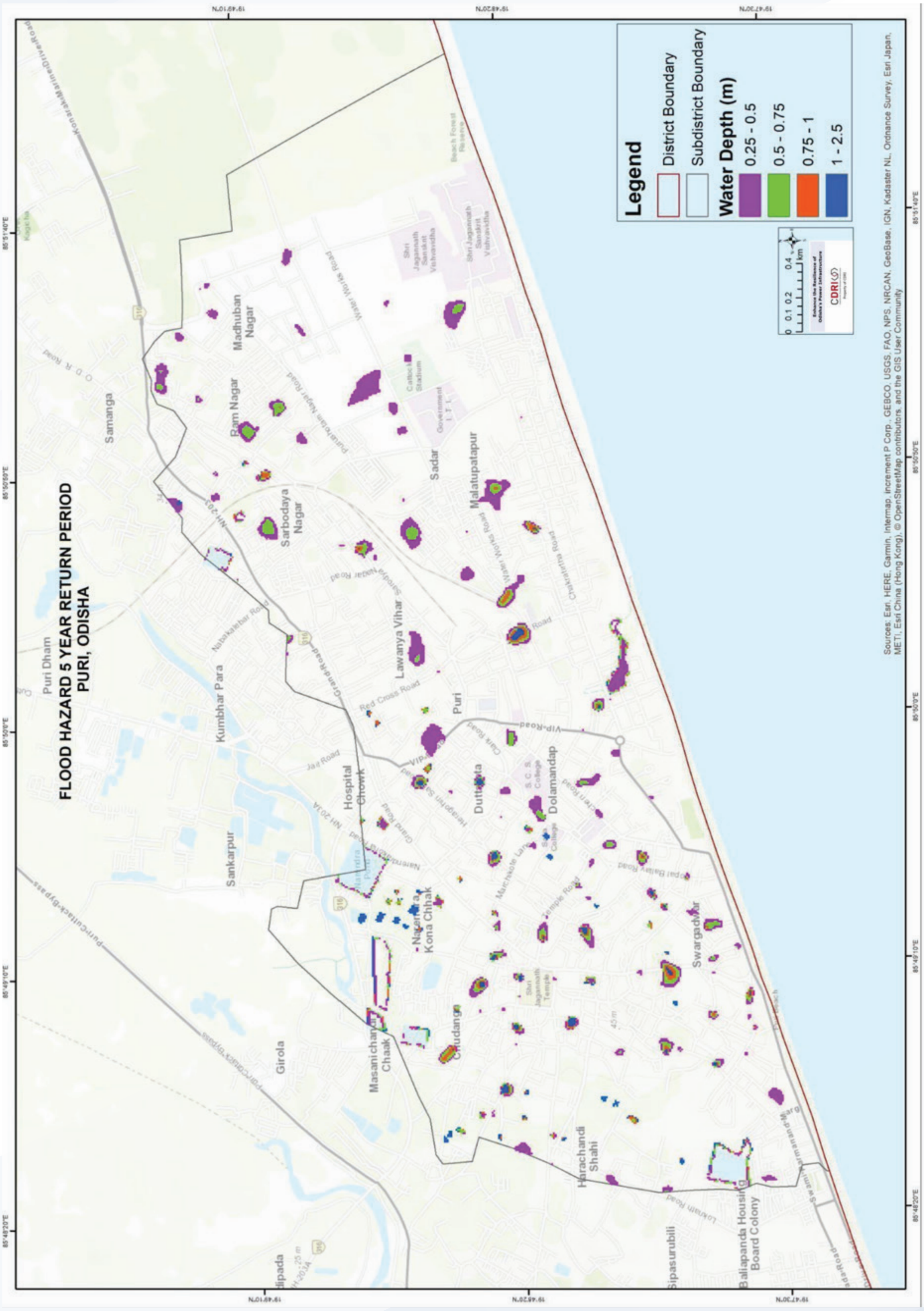


Figure A29: Flood zonation map-1 in 25 years return period (Puri city)

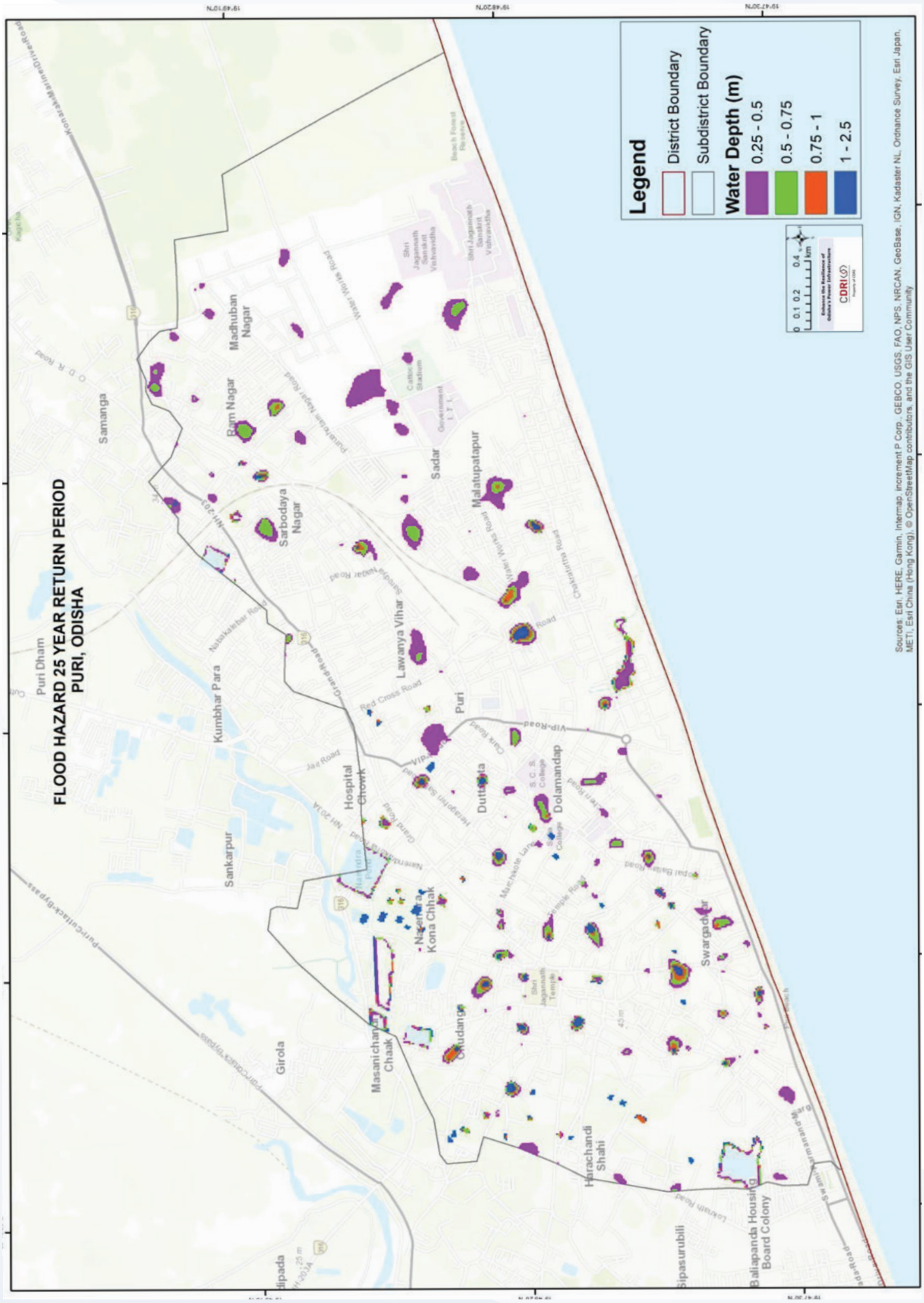


Figure A30: Flood zonation map-1 in 50 years return period (Puri city)

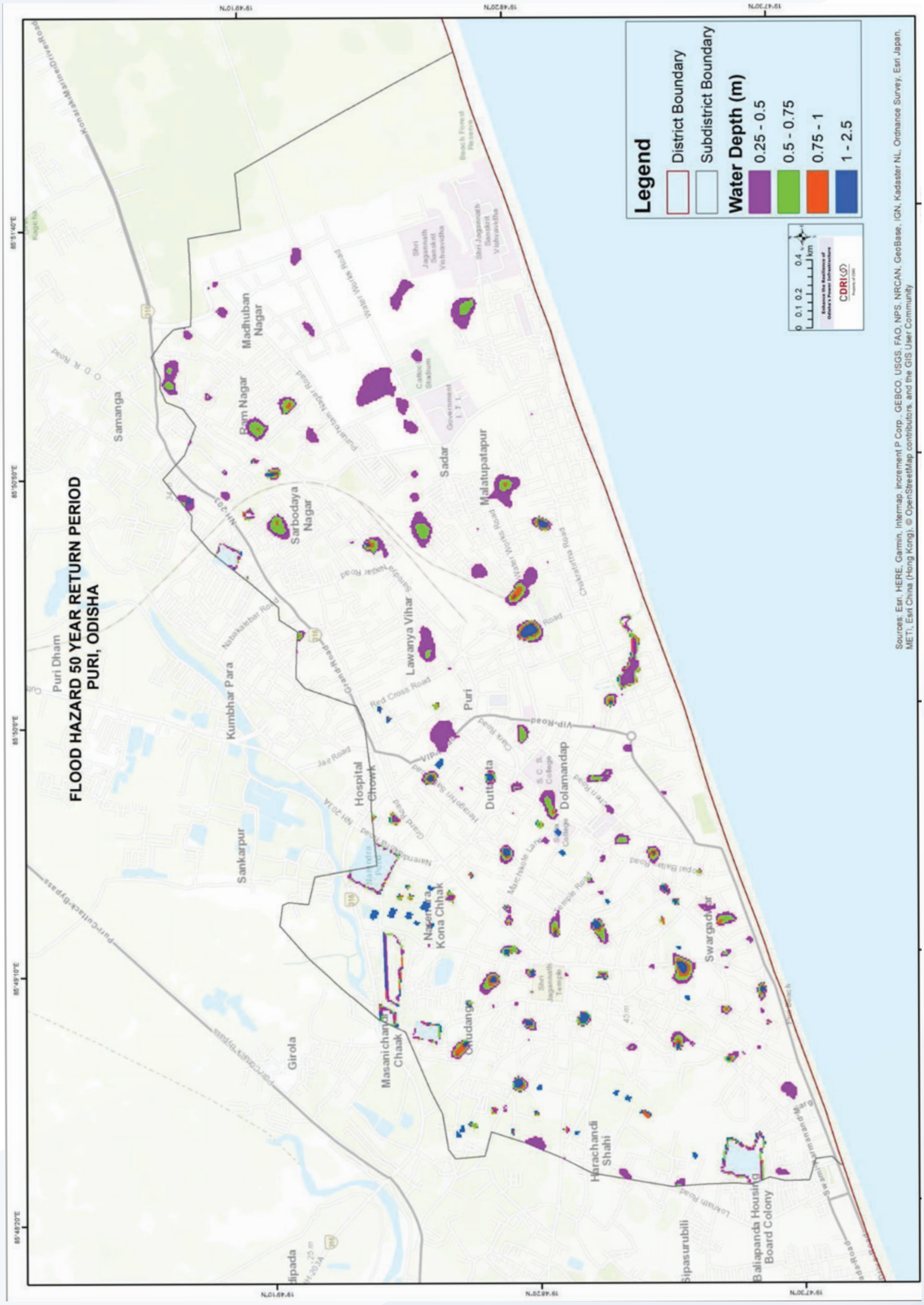


Figure A31: Flood zonation map-1 in 100 years return period (Puri city)

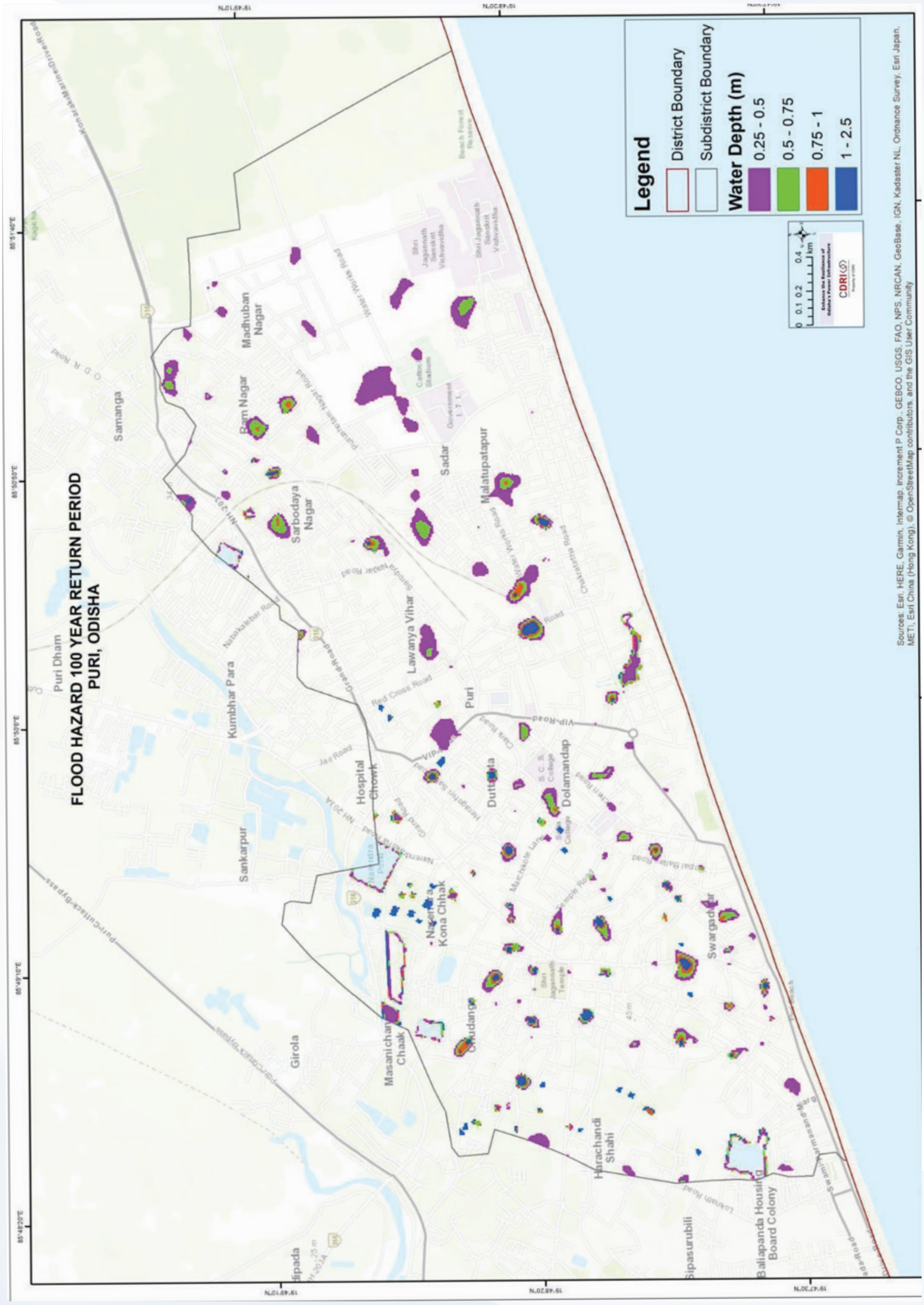


Figure A32: Flood zonation map-future scenario (1 in 5 years return period in Puri city)

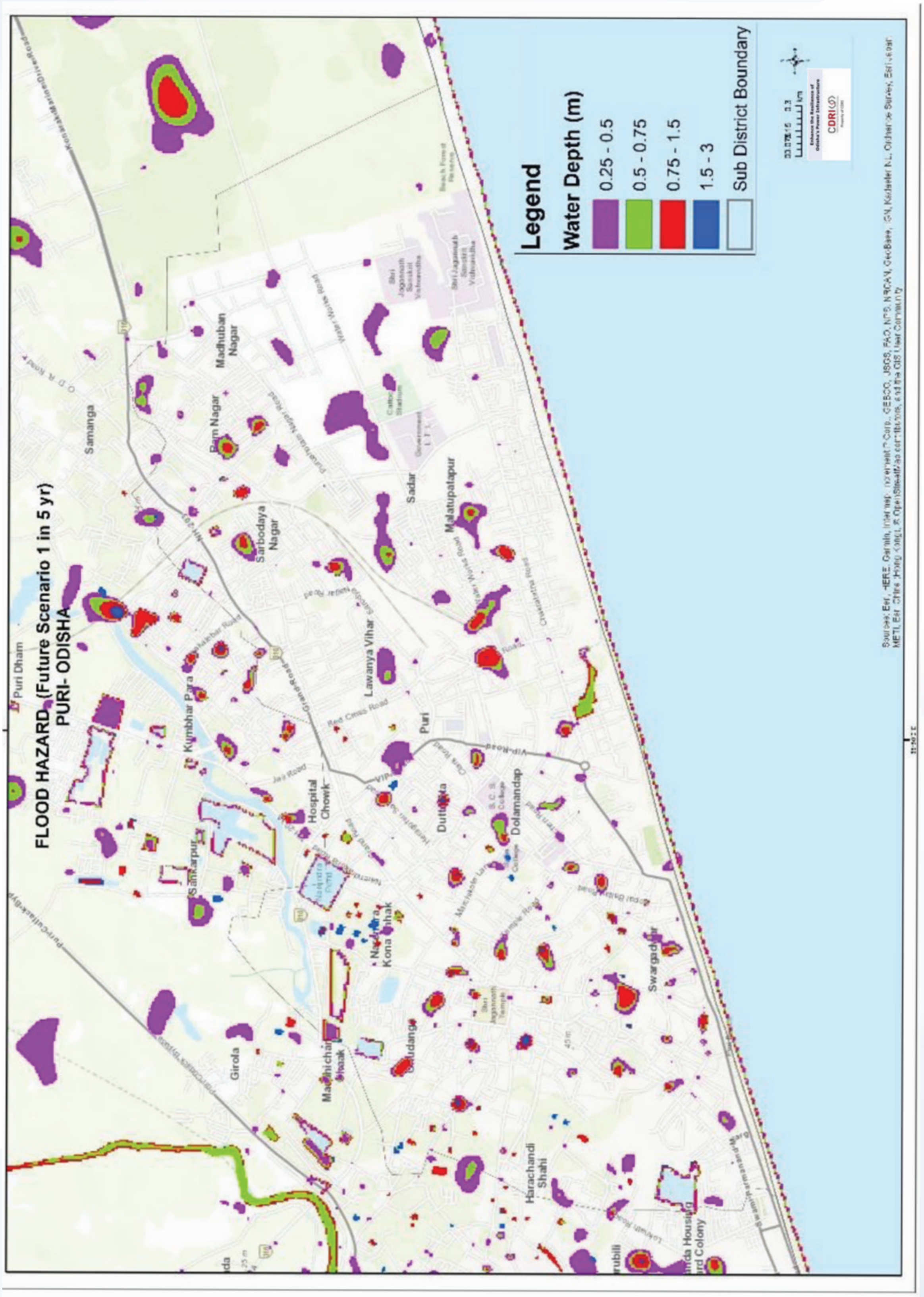
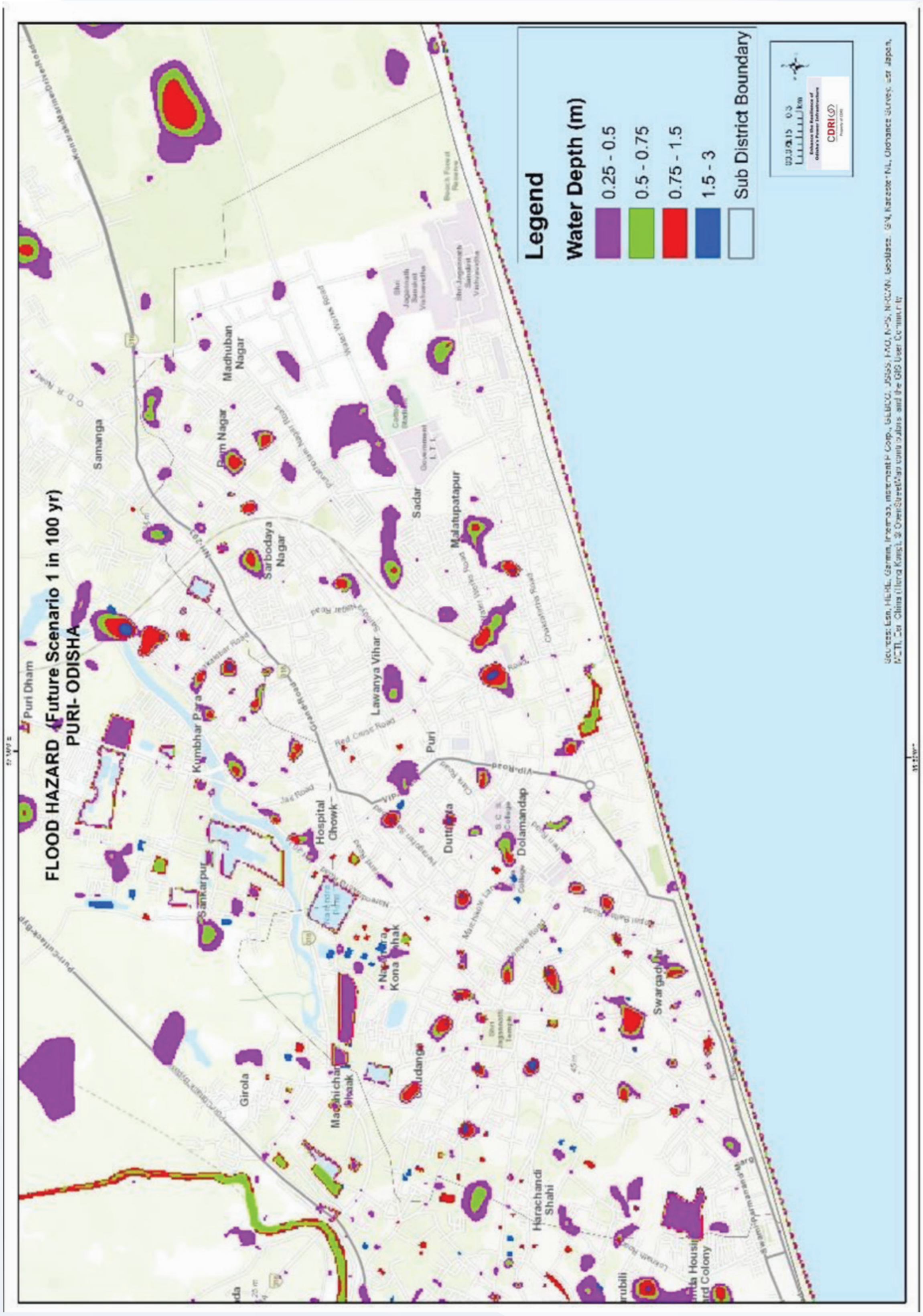


Figure A33: Flood zonation map-future scenario (1 in 100 years return period in Puri city)



Annexure 3: Vulnerability and Risk Assessment

Cyclone Vulnerability of Type of Distribution Substations (AIS or GIS)

Table A1: Cyclone vulnerability of type of substations (AIS or GIS)

DISCOM/Districts	0-20 km				20-60 km				>60 km			
	GIS	AIS ID	AIS [ID -11 kV and OD-33 kV]	AIS OD	GIS	AIS ID	AIS [ID -11 kV and OD-33 kV]	AIS OD	GIS	AIS ID	AIS [ID -11 kV and OD-33 kV]	AIS OD
TPCODL	2%	11%	2%	9%	2%	24%	0%	5%	0%	43%	0%	2%
Angul	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
Cuttack	0%	0%	0%	0%	0%	0%	0%	0%	0%	92%	0%	8%
Dhenkanal	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
Jagatsinghpur	0%	5%	20%	50%	0%	0%	0%	25%	0%	0%	0%	0%
Kendrapada	0%	13%	9%	56%	0%	0%	3%	19%	0%	0%	0%	0%
Khordha	0%	9%	0%	0%	6%	79%	0%	5%	0%	0%	0%	0%
Nayagarh	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
Puri	19%	72%	0%	0%	0%	9%	0%	0%	0%	0%	0%	0%
TPNODL	1%	34%	0%	0%	1%	27%	0%	0%	1%	37%	0%	0%
Balasore	3%	93%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%
Bhadrak	0%	24%	0%	0%	3%	73%	0%	0%	0%	0%	0%	0%
Jajpur	0%	8%	0%	0%	3%	16%	0%	0%	0%	74%	0%	0%
Keonjhar	0%	0%	0%	0%	0%	26%	0%	0%	2%	71%	0%	0%
Mayurbhanj	0%	15%	0%	0%	0%	33%	0%	0%	2%	50%	0%	0%
TPSODL	5%	33%	0%	0%	6%	45%	0%	0%	4%	8%	0%	0%
Gajapati	5%	5%	0%	0%	9%	82%	0%	0%	0%	0%	0%	0%
Ganjam	5%	40%	0%	0%	5%	35%	0%	0%	5%	11%	0%	0%

ID: In-door
OD: Out-door

Table A2: Cyclone vulnerability of type of substations (single or multi/double storey)

DISCOM/Districts	0-20 km		20-60 km		>60 km	
	Single-Storey Building	Double-Storey Building	Single-Storey Building	Double-Storey Building	Single-Storey Building	Double-Storey Building
TPCODL	24%	0%	31%	0%	44%	0%
Angul	0%	0%	0%	0%	100%	0%
Cuttack	0%	0%	0%	0%	100%	0%
Dhenkanal	0%	0%	0%	0%	100%	0%
Jagatsinghpur	75%	0%	25%	0%	0%	0%
Kendrapada	78%	0%	22%	0%	0%	0%
Khordha	9%	0%	91%	0%	0%	0%
Nayagarh	0%	0%	0%	0%	100%	0%
Puri	91%	0%	9%	0%	0%	0%
TPNODL	31%	4%	27%	0%	38%	0%
Balasore	82%	15%	3%	0%	0%	0%
Bhadrak	24%	0%	76%	0%	0%	0%
Jajpur	8%	0%	18%	0%	74%	0%
Keonjhar	0%	0%	26%	0%	74%	0%
Mayurbhanj	15%	0%	33%	0%	52%	0%
TPSODL	37%	0%	50%	0%	12%	0%
Gajapati	9%	0%	91%	0%	0%	0%
Ganjam	45%	0%	40%	0%	15%	0%

Table A3: Length of circuit vulnerable in relation to distance from seacoast w.r.t year of commissioning

DISCOM/Districts	0-20 km				20-60 km				>60 km			
	<30 Year	Length (ckm)	>30 Year	Length (ckm)	<30 Year	Length (ckm)	>30 Year	Length (ckm)	<30 Year	Length (ckm)	>30 Year	Length (ckm)
TPCODL	3%	116	25%	856	18%	337	13%	356	44%	887	24%	630
Angul	0%		0%		0%		0%		100%	298	54%	142
Cuttack	0%		0%		0%		0%		100%	258	54%	290
Dhenkanal	0%		0%		0%		0%		100%	255	39%	175
Jagatsinghpur	0%		85%	255	0%		15%	59	0%		0%	
Kendrapada	0%		79%	295	0%		21%	44	0%		0%	
Khordha	10%	116	1%	10	62%	337	28%	211	0%		0%	
Nayagarh	0%		0%		0%		0%		100%	77	22%	22
Puri	0%		83%	296	0%		17%	41	0%		0%	
TPNODL	0%		34%	574	0%		34%	726	38%		32%	1,133
Balasore	0%		95%	362	0%		5%	16	0%		0%	
Bhadrak	0%		26%	116	0%		71%	190	0%		3%	27
Jajpur	0%		8%	27	0%		25%	94	74%		67%	282
Keonjhar	0%		0%		0%		27%	101	74%		73%	497
Mayurbhanj	0%		13%	70	0%		56%	324	52%		31%	327
TPSODL	14%	164	18%	364	8%	107	43%	674	12%	119	13%	181
Gajapati	3%	5	3%	0	0%		61%	262	0%	99	21%	68
Ganjam	17%	159	23%	364	10%	107	37%	402	15%	20	10%	113

Table A4: Length in km for line failed during past hazards w.r.t its distance from seacoast

DISCOM/Districts	0-20 km				20-60 km				>60 km			
	Failed in Past	Length of Circuit Failed	Not Failed in Past	Length of Circuit Not Failed	Failed in Past	Length of Circuit Failed	Not Failed in Past	Length of Circuit Not Failed	Failed in Past	Length of Circuit Failed	Not Failed in Past	Length of Circuit Not Failed
TPCODL	17%	616	11%	356	15%	280	17%	413	1%	42	39%	1,476
Angul	0%		0%		0%		0%		0%		100%	440
Cuttack	0%		0%		0%		0%		3%	26	97%	523
Dhenkanal	0%		0%		0%		0%		0%		100%	430
Jagatsinghpur	76%	240	9%	15	15%	59	0%		0%		0%	
Kendrapada	76%	283	3%	12	21%	44	0%		0%		0%	
Khordha	1%	2	10%	124	39%	176	50%	372	0%		0%	
Nayagarh	0%		0%		0%		0%		11%	16	89%	83
Puri	20%	91	63%	205	0%		17%	41	0%		0%	
TPNODL	34%	574	0%		34%	726	0%	-	26%	844	6%	289
Balasore	93%	362	2%		5%	16	0%		0%		0%	
Bhadrak	26%	116	0%		71%	190	0%		3%	27	0%	
Jajpur	8%	27	0%		25%	94	0%		67%	282	0%	
Keonjhar	0%		0%		27%	101	0%		73%	497	0%	
Mayurbhanj	13%	70	0%		54%	324	2%	-	7%	39	24%	289
TPSODL	0%		32%	529	0%		51%	782	0%		17%	300
Gajapati	0%		6%	6	0%		61%	262	0%		33%	167
Ganjam	0%		41%	523	0%		47%	509	0%		12%	133

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