United Nations Development Programme

Multi-Hazard Risk and Vulnerability Assessment (HRVA) for City of Cuttack, Odisha

Final Report

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For the kind attention of:

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We would also like to acknowledge our sincere gratitude to the Cuttack City Commissioner and his team including the city UNDP officer for extending all support including facilitating data collection, engaging in discussions, and providing city specific information which were of immense help for finalizing the study.

Executive Summary

The Hazard Risk and Vulnerability Analysis (HRVA) for the city of Cuttack, Odisha is being carried out as part of the on-going GOI-UNDP Disaster Risk Reduction (DRR) Programme aimed at strengthening the institutional structure to undertake disaster risk reduction activities at various levels, and develop preparedness for recovery. The assignment assesses hazard risks with a focus on climate related hazards and how they are likely to be impacted by climate change. The output of this assignment aims to integrate DRR initiatives in city development including strengthening the institutional capacity for DRR activities and risk resilient urban planning.

City Profile:

Cuttack, the commercial capital of Odisha, is one of the oldest cities and is located at the confluence of two big rivers, namely, the Mahanadi in the north and Kathajodi and is about 30 km away from the State capital. It has a population of 6.5 lakhs (2017) distributed among 59 wards with a spatial spread of 82.43 sq km. It has a population density of about 7,823 people per sq km with trade and commerce as the key economic activities.

City Assets:

The city has 1.97 lakh households with a total population of about 6.5 lakhs. About 74% of the buildings in the city are being used for residential purposes, while commercial and industrial establishments account for about 23% and 4% of the total building use, respectively. Among the residential houses, reinforced concrete frame with brick infill is the dominant structural type and accounts more than 87% buildings in this category. The total exposure value of residential buildings is estimated at around INR 7,205 crores.

There are 870 educational institutions in the city. They comprise of schools, colleges, universities, and other educational institutes. The total estimated exposure value for educational institutions is estimated at INR 792 crores. There are 672 health facility centers in the city with a total estimated exposure value estimated at INR 344 crores. The total estimated exposure value for the road network in the city is INR 2,268 crores and for the railway network is estimated at INR 265 crores.

Hazard mapping and analysis:

The city is vulnerable to cyclone, flood, earthquake, and heat wave that affect the socio economics of the city. The city was impacted severely by the 1999 Super Cyclone and the floods of 1982, 2008 and 2011. The historical cyclone event data shows that 142 cyclonic disturbances passed within 100 km of the city of which the maximum wind speed experienced was 258 km/h. The recent cyclone that affected the city was the Phailin cyclone of 2013 when the city experienced a wind speed of 215 km/h. The impact was mostly in terms of damage to assets, particularly infrastructure and houses. The modeled results of the cyclone hazard show that wind speed varies from 204 km/h in the south to 213 km/h in the north for a 100-year return period event. While considering climate change, which can increase the frequency and intensity of the wind hazard, the city could experience a minimum wind speed of 264 km/h in the south to 277 km/h in the north in the extreme scenario (500 year-return period event with 7% projected increase in the intensity of cyclone by mid-century).

Considering the location of the city in the delta area, the city is vulnerable to flooding. Flooding is due to heavy localized rainfall as well as discharge of water from the Hirakund dam located 330 km upstream. The topography of the city is saucer shaped with unplanned urban development and choking of the narrow drains with solid waste causing frequent water logging problems in many parts of the city. The flood analysis shows that Ward Nos. 2, 3, 9, 14, 17, 20, 26, 33, 40, 43 are especially vulnerable to flooding/water logging conditions. The city operates pumps to pump out water during rainy season to avoid water logging. The city, under various development projects, is also developing drains to reduce the impact of flood and

water logging. Climate change can intensify rainfall, which can influence the runoff thus increasing flood vulnerability.

Extremely high-rise in annual average maximum temperature, continuous increase in the number of hot days and rising temperature difference between Cuttack and the nearby cities provides an impression of the gradual emergence of the city as an urban heat island. During May 2013, Cuttack recorded a maximum temperature of 44.5°C. Subsequently, heat stress conditions prevailed in the Cuttack District. Most of the districts in Odisha, on an average, recorded 40ºC during April 2014 and the temperature across a few districts in coastal Odisha reached 46ºC by the end of May. Very severe heat stress conditions prevailed in May/June months. Increasing trends have been reported in observed maximum (daytime high) and minimum (nighttime low) surface temperatures at Cuttack during the past 50 years.

Cuttack city is located in seismic zone-III, which is moderately vulnerable to earthquakes. However, minor to moderate earthquakes, not of damaging scale, have occurred in the past at different localities. Recently, on May 21, 2014 an earthquake of magnitude 6 on the Richter scale occurred in the Bay of Bengal, and shock was felt in different parts of Cuttack and neighboring cities due to local soil-amplifications, though there was no report of any significant damage in the city. The Global Seismic Hazard Analysis Program (GSHAP) provides probabilistic seismic hazard values in and near Cuttack city of about 0.13 g corresponding to 10% probability of exceedance in 50 years (475 years return period) at base rock level indicating that PGA values are almost the same for the entire city.

Considering the high-density of population, traditional houses, and high temperatures in the summer months, the city is vulnerable to fire accidents. Historical fire accident data shows that the occurrence of fire hazard incidence is higher in residential buildings compared to commercial and industrial buildings.

Climate change analysis shows projected annual mean warming of about 4.6°C by the end of this century over Cuttack with increases in the number of hot days and warmer nights. The total count of warmer nights is expected to increase on an average by about 17 days over Cuttack by the end of this century. During pre-monsoon and monsoon seasons, the increase in number of nights with warmer nighttime surface air temperatures is projected at all-time slices. The projected change in the number of warmer nights over Cuttack is likely to be least during post-monsoon season during 2050s and beyond. Maximum number of days with increase in warm nights spatially averaged over Cuttack at all-time slices appears to occur in the months of July-August in a year.

The analysis on an annual mean basis shows that as much as 26 mm per month of rainfall could be added to the present-day monthly mean due to an increase in wet days with total rainfall being in excess of the 95th percentile. The rainfall exceeding 95th percentile during the monsoon season could add about 60 mm of monthly total rainfall by the end of the 21st century. This could have serious implications in the form of more frequent and severe floods in Cuttack in the future.

Application of hazard maps for city development and disaster management:

The hazard mapping and analysis help in identifying areas those are prone to various hazards – both in terms of intensity and in terms of probability. This will help city in taking appropriate site-specific short, medium, and long-term mitigation measures.

Hazard maps help city planners to take proactive mitigation and adaptation measures to reduce hazard risk vulnerability. The composite hazard maps will help in identifying hotspots in the city to carryout risk resilient urban planning. As the behavior of hazards varies from hazard to hazard, hazard-specific interventions are required.

Climate change projections provide expected variations in climate parameters that need to be considered while defining forward looking urban master plan for Cuttack.

Vulnerability Assessment:

The physical vulnerability analysis derives damage functions of key structural types, which will be integrated in the risk assessment model. The RVS survey shows that there is a large number of masonry residential and commercial structures with poor maintenance that are vulnerable to hazards particularly earthquake. The analysis shows that about 20% of the residential structures need detailed structural analysis.

The social vulnerability analysis shows that wards with slum pockets and wards where density of population are having higher social vulnerability index. Interestingly, the population growth of the city shows a declining trend. Incidence of jaundice is higher in the recent past along with vector-borne diseases – dengue and malaria. The city lacks systematic centralized documentation of disease data. The central island area of the city is now saturated by built-up and further horizontal growth is constrained due the presence of rivers on all sides. The wetlands, including ponds, either are silted or reclaimed thus increasing the flood risk to the city.

Vulnerability data will be used along with exposure and hazard data for the risk assessment exercise.

Risk assessment:

Cyclone wind hazard risk assessment: The estimated losses (PML) due to wind hazard (while considering 1% annual occurrence of cyclonic wind event) is estimated at about INR 884.96 crores, INR 279.21 crores, and INR 562.65 crores for residential, commercial, and industrial buildings respectively. While estimating the industrial losses, it was found that they are mostly concentrated in ward numbers 49, 50, 42, 59, 48, 54 and 56. The combined annual average loss (of all sectors) is highest for wards 49 and 50 along with wards 42, 46, 56, 57, 59.

The analysis of climate change projections show that the globally averaged intensity of tropical cyclones will shift towards stronger storms, with intensity increases of 2-11% by 2100. If we consider this scenario for Cuttack city, the losses are expected to increase in the range of 27% to 42% while considering the 1% annual occurrence event and without considering any growth in the sectors. However, if we consider growth in the sectors until 2100, the impact would be much higher.

Flood hazard risk assessment: The estimates of potential losses (PML) due to flood hazard are significant for residential and commercial occupancies when compared to industrial losses. The losses in both residential and commercial occupancies consistently increase from higher probabilities of occurrence to lower probabilities of occurrence. The losses are expected to almost double from 2% probability to 1% probability. For 1% annual occurrence flood, the losses are estimated at INR 22.66 crores, INR 3.68 crores, and INR 0.11 crores for residential, commercial, and industrial occupancies respectively.

The analysis shows that flood losses are expected to double under the impact of climate change for high occurrence flood events. However, for extreme events, such as 1% annual occurrence floods, the losses are expected to increase between 10% to 16%.

Earthquake risk assessment: The PML for buildings were estimated based on occupancy and replacement costs for different building types. The estimated loss scenario of 475-year return period is to the order of INR 785 crores (8% of total exposure value) for residential buildings, INR 513 crores (17% of total exposure value) for commercial buildings, and INR 571 crores (24% of total exposure value) for industrial buildings. The sector-wise analysis shows the maximum losses are in education institutions (to the order of INR 74 crores). For hospitals and places of worship, the estimated PML losses are to the order of INR 32 crores and INR 5 crores, respectively for this scenario event.

Risk Hotspots in the city: The “Composite High Risk Hotspots Analysis” categorizes the city into high, medium, and low vulnerability areas based on the cumulative score of all the hazards considered for the analysis. Wards with high risk need priority interventions. About 31% of the population in the city is living in high-risk wards.

Capacity Assessment: The City administration needs to strengthen the capacity of middle-level officers and develop stronger mechanisms for monitoring the implementation of hazard resilient development. The City also needs to develop strategies to decongest the city center and put in place an effective mechanism for solid waste management, which are critical for effective flood management. Coordination between various departments needs to be strengthened to improve hazard risk resilience of the city.

The community organizations are weak in the city and need orientation and training to work among communities. The level on awareness on DRR and CCA within communities is also very poor.

The city needs to emphasize on hazard risk-based urban planning than a planning process that is purely driven by economic aspects.

Priority Areas for Risk Reduction and Action Plan to Build Resilience:

Priority areas for risk reduction and action plan developed is based on the disaster risk and should emphasis on the key components of disaster risk reduction. It is aligned with recently implemented projects and ongoing projects. The intervention should be a mix of structural and non-structural one and should be implemented short, medium and long term plan. Mainstreaming DRR and CC in development planning is critical and is required for Cuttack city.

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Abbreviations Used

AHP	Analytic Hierarchy Process
AAL	Average Annualized Losses
ASI	Archaeological Survey of India
BCSD	Bias-Corrected Spatial Disaggregation
BMTPC	Building Material Technology Promotion Council of India
BSNL	Bharat Sanchar Nigam Limited
CBA	Cost-Benefit-Analysis
CCA	Climate change adaption
CDA	Cuttack Development Authority
CDMP	City Disaster Management Plan
CDP	City Development Plan
CMC	Cuttack Municipal Corporation
CMIP5	Coupled Model Inter-comparison Project Phase 5
CRU	Climate Research Unit
DEM	Digital Elevation Model
DPR	Detailed Project Report
DRR	Disaster Risk Reduction
DTR	Diurnal Temperature Range
EP	Exceedance Probability
FSI	Floor Space Index
GAA	Gopabandhu Academy of Administration
GSHAP	Global Seismic Hazard Analysis Program
HEC RAS	Hydrologic Engineering Centre's River Analysis System
HRVA	Hazard Risk and Vulnerability Assessment
IDRN	India Disaster Resource Network
IMD	India Meteorological Department
IMD	India Meteorological Department
INR	Indian Rupees
IREE	International Railway Equipment Exhibition
LEC	Loss Exceedance Curve
MDR	Mean Damage Ratio
MHA	Ministry of Home Affairs
NDRF	National Disaster Response Force
NEX-GDDP	NASA Earth Exchange Global Daily Downscaled Projections
NGO	Non-Governmental Organization
NHAI	National Highway authority of India
NUHM	National Urban Health Mission
ODRAF	Odisha Disaster Rapid Action Force
OSDMA	Odisha State Disaster Management Authority
PGA	Peak Ground Acceleration
PMGSY	Pradhan Mantri Gramin Sadak Yojna

PML	Probable Maximum Losses
PWD	Public Works Department
SCR	Stable Continental Region
SHG	Self-Help Group
SIRD	State Institute for Rural Development
SOP	Standard Operating Procedures
SoVI	Social Vulnerability Index
TRAI	Telecom Regulatory Authority of India
URG	Uniform Resolution Grids

Key Concepts and Terminologies

Some key concepts to help readers to understand the terminology and application of disaster risk assessment in city planning is provided below. This section is an extract from PreventionWeb of UNISDR http://www.preventionweb.net/risk/deterministic-probabilistic-risk

Return period represents the annual probability of having a loss of this size every year. The annual probability of exceeding a loss characterized by a 100-year return period is 1% - the inverse of the return period (1/100*100).

Deterministic risk considers the impact of a single risk scenario. This approaches are used to assess disaster impacts of a given hazard scenario

Probabilistic risk considers all possible scenarios, their likelihood and associated impacts. This method is used to obtain more refined estimates of hazard frequencies and damages. Probabilistic assessments are characterized by inherent uncertainties, partly related to the natural randomness of hazards, and partly because of our incomplete understanding and measurement of the hazards, exposure and vulnerability under consideration (OECD, 2012). Probabilistic risk assessment simulates those future disasters which, based on scientific evidence, are likely to occur (UNISDR, 2015). As a result, these risk assessments resolve the problem posed by the limits of historical data (UNISDR, 2015). Probabilistic models therefore "complete" historical records by reproducing the physics of the phenomena and recreating the intensity of a large number of synthetic events (UNISDR, 2015).

In contrast, a deterministic model treats the probability of an event as finite. The deterministic approach typically models scenarios, where the input values are known and the outcome is observed.

There are a number of problems with a deterministic approach, including the fact that it does not consider the full range of possible outcomes, and does not quantify the likelihood of each of these outcomes. Consequently, deterministic scenario planning may actually be under estimate the potential risk. In order to address this short-fall, we have to adopt a probabilistic approach.

Probabilistic risk is the chance of something adverse occurring. This method assesses the likelihood of an event(s) and it contains the idea of uncertainty because it incorporates the concept of randomness.

Deterministic approach can be used to test an evacuation plan or mitigation strategy against a selected event. However, even if we are interested in knowing a specific risk scenario for a specific event, we can obtain this from a probabilistic assessment. In fact, probabilistic approaches allow us to identify and model scenarios whilst also accounting for their return period. Measuring the likelihood of events means that decision-makers are more informed and better able to select appropriate strategies for different scenarios, e.g. risk reduction in the case of extensive risks and risk transfer in the case of more high-impact (but less likely) events.

Probabilistic risk assessments are increasingly becoming the standard for disaster risk assessment because they are the more comprehensive approach. These assessments provide us with a means of quantifying the impact and likelihood of events, while also accounting for the associated uncertainty.

Uncertainty: Few findings from natural and social science are 100% certain, owing to the natural randomness of hazards and the fact that information and understanding of processes is incomplete. In spite of this, we still have to make decisions for building resilience. The level of uncertainty is directly linked to the quality of the input data. In addition, there is also random uncertainty that cannot be reduced. On many occasions during model development, expert judgment and proxies are used in the absence of historical data, and the results are very sensitive to most of these assumptions and variations in input data.

A risk model can produce a very precise result - it may show, for example, that a 1-in-100-year flood will affect 388,123 people - but in reality, the accuracy of the model and input data may provide only an order of magnitude estimate.

We should not be apprehensive of using information that is uncertain so long as any decisions and actions based upon the information are made with a full understanding of the associated uncertainty and its implications.

Model deterministic and probabilistic risk: We model risk both deterministically and probabilistically using a series of components (sometimes called modules) for hazard, exposure, vulnerability and loss (or impact). In deterministic models, the output of the model is fully determined by the parameter values and the initial values, whereas probabilistic (or stochastic) models incorporate randomness in their approach. Consequently, the same set of parameter values and initial conditions will lead to a group of different outputs. We can also use probabilistic risk models to do a deterministic analysis by entering the parameters of the specific hazard event.

A deterministic risk (or impact) analysis will provide a robust estimation of the potential building damage, mortality/morbidity, and economic loss from a single hazard scenario (GFDRR, 2014). Probabilistic risk models are used when an event set contains a sufficient number of events for the estimate of the risk to converge at the longest return period, or the smallest probability, of interest (GFDRR, 2014). Note that we cannot wholly rely on our knowledge of past events to anticipate future risk, because some disasters that could happen have not yet happened.

A probabilistic approach minimizes these limitations. It uses historical events, expert knowledge, and theory to simulate events that can physically occur but are not represented in the historical record.

The results of probabilistic risk models are normally presented in terms of standard measures (metrics) such as average annual loss (AAL). AAL is the expected average loss per year considering all the events that could occur over a long time frame. It is a compact metric with a low sensitivity to uncertainty. Unlike historical estimates, AAL takes into account all the disasters that could occur in the future, including very intensive losses over long return periods, and thus overcomes the limitations associated with estimates derived from historical disaster loss data. Most probabilistic risk assessments have been developed commercially for the insurance industry and cover specific risks, mainly in higher-income countries (UNISDR, 2015).

Probable Maximum Losses (PMLs) can be expressed as the probability of a given loss amount being exceeded over different periods of time. Thus, even in the case of a thousand-year return period, there is still a 5% probability of a PML being exceeded over a 50-year time-frame. This metric is relevant for planners and designers of infrastructure projects, where investments may be made for an expected lifespan of 50 years (UNISDR, 2015). The outputs of these models should be considered indicators of the order of magnitude of the risks, not as exact values. Better data quality and advances in science and modelling methodologies reduce the level of uncertainty, but it is crucial to interpret the results of any risk assessment against the backdrop of unavoidable uncertainty (UNISDR, 2015).

1 Introduction

1.1 Background

Cuttack city, the former capital of Odisha, and one of the oldest cities of the State. It is spread across an area of 192.5 km^2 and has an average elevation of 36 meters above mean sea level (MSL). The city is the commercial capital of the State, which hosts a large number of trading and business houses in and around the city. The city is characterized by narrow streets and crowded old buildings. Though it is experiencing fast economic growth, there are constraints in developing infrastructure essential for commercial activities. The city's growth is also constrained due to its geographic location in a deltaic island. The last one decade has witnessed development spilling beyond this main island towards the north and south that are sparsely populated. Being an old city, the growth has been largely in an unplanned manner.

Due to the proximity to coast, the city is prone to cyclones from the Bay of Bengal. The 1971 cyclone that struck Cuttack and the 1999 Super Cyclone have resulted in more than 10,000 deaths each. The Bureau of Indian Standards places Cuttack city in seismic zone III on a scale ranging from I to V in order of increasing susceptibility to earthquakes (IS 1893, 2002).

Floods also play regular havoc with the city. On 7 August 2007, Cuttack received 437 mm of rainfall, a 50-year record. The torrential rains in the city led to at least 50,000 people being trapped in their waterlogged homes and killed 15 people including six who were struck by lightning in Cuttack. The entire state of Odisha was ravaged by floods again in June and September during the year 2008, which led to an unprecedented calamity of rare severity. The water level recorded in the Subarnarekha exceeded all the past records. The flood in September 2008 was due to heavy rainfall in the upper as well as lower catchments of the Mahanadi River resulting from a deep depression in the Bay of Bengal from 16^{th} to 21^{st} September 2008. In September 2011 again, flood's fury in the Mahanadi and other rivers wreaked havoc in the State, including Cuttack.

A drought of moderate to severe nature occurs in Odisha once in almost 8 years on an average. Although several severe droughts have occurred in the past, the drought of 2000-2001 assumes great significance due to its magnitude and severity. Odisha, including Cuttack, will continue to be a drought-ravaged state in the 21st century as global warming enhances summer monsoon variability.

The impacts of climate change add a new and more intractable dimension to the existing risk profile of vulnerable urban cities in India as it may alter the number, frequency and severity of weather and climate induced hazards.

It is worth noting that the State has taken remarkable steps towards Disaster Risk Reduction (DRR) since the super cyclone of 1999 devastated the state. These DRR initiatives have done well to secure the economic growth in the State and have proved its capability to develop disaster response and recovery mechanisms at par with international best practices especially, to cope with cyclone and heat wave hazards.

Nevertheless, in the broader perspective, it remains critical to adopt an integrated climate change risk management to understand extreme events and build-in disaster risk reduction in local development policies. The on-going Government of India-UNDP Disaster Risk Reduction Programme aims to strengthen the institutional structure to undertake disaster reduction activities at various levels, and develop preparedness for recovery. In this context, the current assignment is to undertake hazard risk and vulnerability analysis for the city of Cuttack in Odisha State with a focus on climate related hazards.

1.2 Scope of the Assignment

The study has various components as detailed below and is further detailed out in various chapters of this report:

1. Component 1: Multi-Hazard Mapping and Analysis
2. Component 2: Development of Exposure Database at City level with ward level resolution
3. Component 3: Vulnerability Assessment
4. Component 4: Risk Assessment
5. Component 5: Capacity Assessment at community, ward, and city levels
6. Component 6: Priority Areas for Risk Reduction and Action Plan to Build Resilience

We tried to keep the analysis and results concise in the main chapters and the detailed methodology, data, and detailed results in annexures of the report.

1.3 Cuttack City Profile

Cuttack, located in the delta of the Mahanadi River, is the commercial capital of Odisha and is one of the oldest cities established during the Kalinga period.

Latitudinal extent	20°21'11.98"N to 20°30'45.97"N
Longitudinal extent	85°46'14.16"E to 85°57'21.55"E
Area	82.43 sq km
Number of wards	59
Weather characteristics	
Average annual rainfall	1,441 mm
Mean annual minimum temperature	20.0⁰ C
Mean annual maximum temperature	32.9⁰ C
Rainy season	June to October
Mean annual humidity	70%
Slums details	
Authorized slums 309	Un-Authorized slums 104
Slum population 2.35 Lakhs (Census, 2011)	No. of slum households 32,106 (Census,2011)
Population	659,122 (2017)
Population density	7,823 person/ sq km (2017)
Key economic activity	Trade and Commerce, Service
No. of households	139,892 (2017)
Literacy rate	82%
Infrastructure	

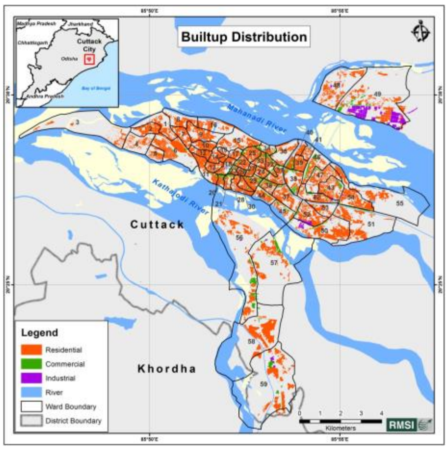


Figure 1-1: Built up map, Cuttack city

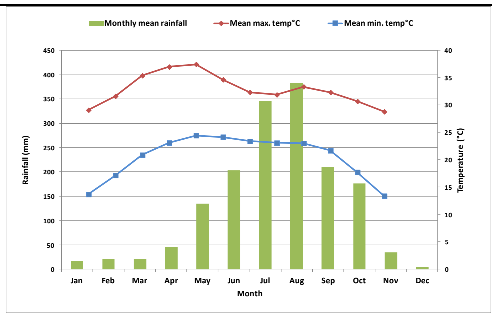


Figure 1-2: Weather profile, Cuttack city

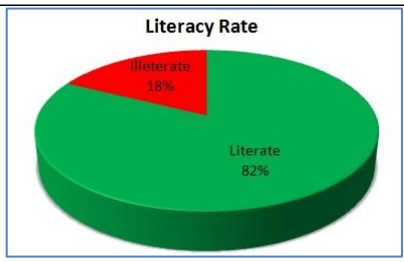


Figure 1-3: Literacy rate, Cuttack city

Figure 1-4: Road network map, Cuttack city

2 Component 1: Multi Hazard Mapping and Analysis

2.1 Identification and Assessment of Hazards

The historical hazard information shows that the city is highly vulnerable to cyclones, floods, and heat waves. Being located in seismic zone-III, the city is moderately vulnerable to earthquakes. There is no record of damaging earthquake events recorded in the past affecting the city.

Hazard and damage information available are mostly at district level. Occurrence of fire accidents is relatively more in residential areas as compared to industrial and commercial areas. Several fire accidents have been reported though not of catastrophic levels. Epidemic outbreaks have not been reported in the city but there are pockets, which have a high incidence of vector (dengue and malaria) and water borne (diarrhea and Jaundice) diseases.

Historical hazard information, including frequency of occurrence and damage, were considered while carrying out detailed hazard assessment. The assessment of hydro metrological hazards, particularly cyclone, flood, and heat wave also factor in the impact of projected climate change in the city.

2.2 Cyclone Hazard Assessment

Cuttack city is often impacted by strong winds and torrential rains associated with tropical cyclones formed in the Bay of Bengal. The 1999 Odisha Super Cyclone was the most severe storm ever recorded in the city, with wind speeds of 258 km/h causing extensive damage to property and loss to human life. The vulnerability due to cyclone hazard over the city can be gauged by analyzing the historical events that occurred from 1877-2016:

- 142 cyclonic disturbances passed within 100 km of Cuttack city
- Of these, 2 were cyclonic storms, 1 was a very severe cyclonic storm, 11 were deep depressions, and 7 were depressions
- The maximum wind speed experienced was 258 km/h.

Besides the above, Cuttack city witnessed several storms (Figure 2-1) ranging from tropical depressions (31-61 km/h) to very severe cyclonic storms (88-260 km/h). The tracks of the 142 historical disturbances (1877-2016) considered for cyclone hazard analysis are shown in Figure 2-1 and a list of these events is shown in Table 8-5 of Annexure 1.

Table 2-1: Number of historical cyclone events considered for Cuttack city (1877-2016)

Category	No. of cyclonic disturbances
Depressions	26
Deep Depressions	63
Cyclonic Storms	41
Severe Cyclonic Storms	2
Very Severe Cyclonic Storms	9
Super Cyclonic Storms	1

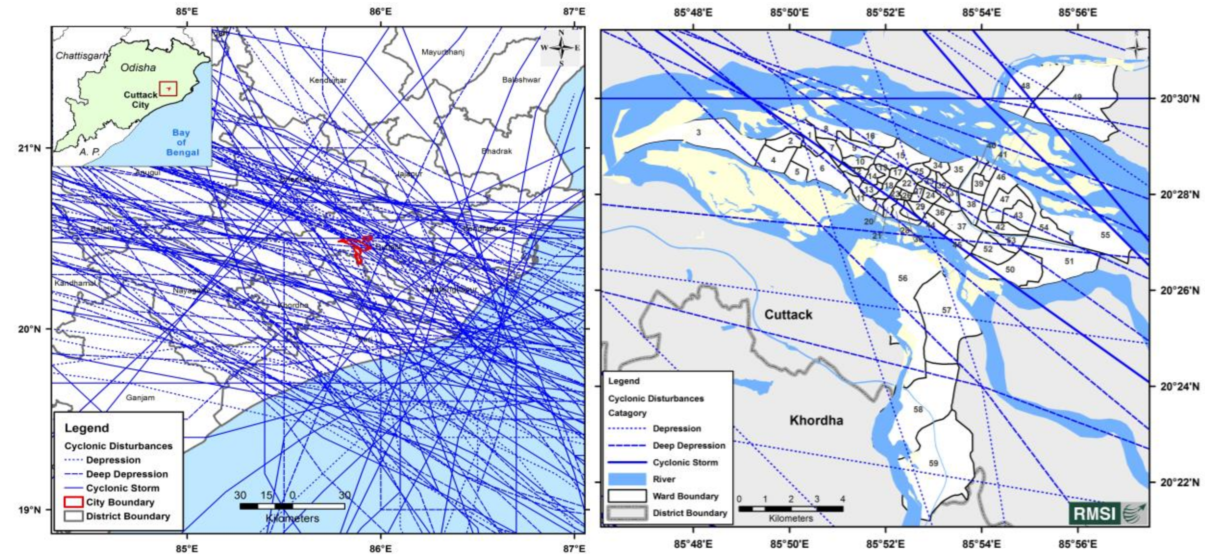


Figure 2-1: Tracks of cyclone events that occurred between 1877-2016 with landfall around Cuttack city (left) and events that crossed the city (right)

2.2.1 WIND HAZARD MAPS PRESENT SCENARIO

Wind hazard maps under present climatic conditions over the city for key return periods, namely, 2, 5, 10, 25, 50, 100, 250 and 500 years were generated through numerical modeling. Ward boundaries were demarcated over hazard maps for analyzing detailed susceptibility in specific regions. The wind hazard maps for 5-year and 100-year return period events are shown in

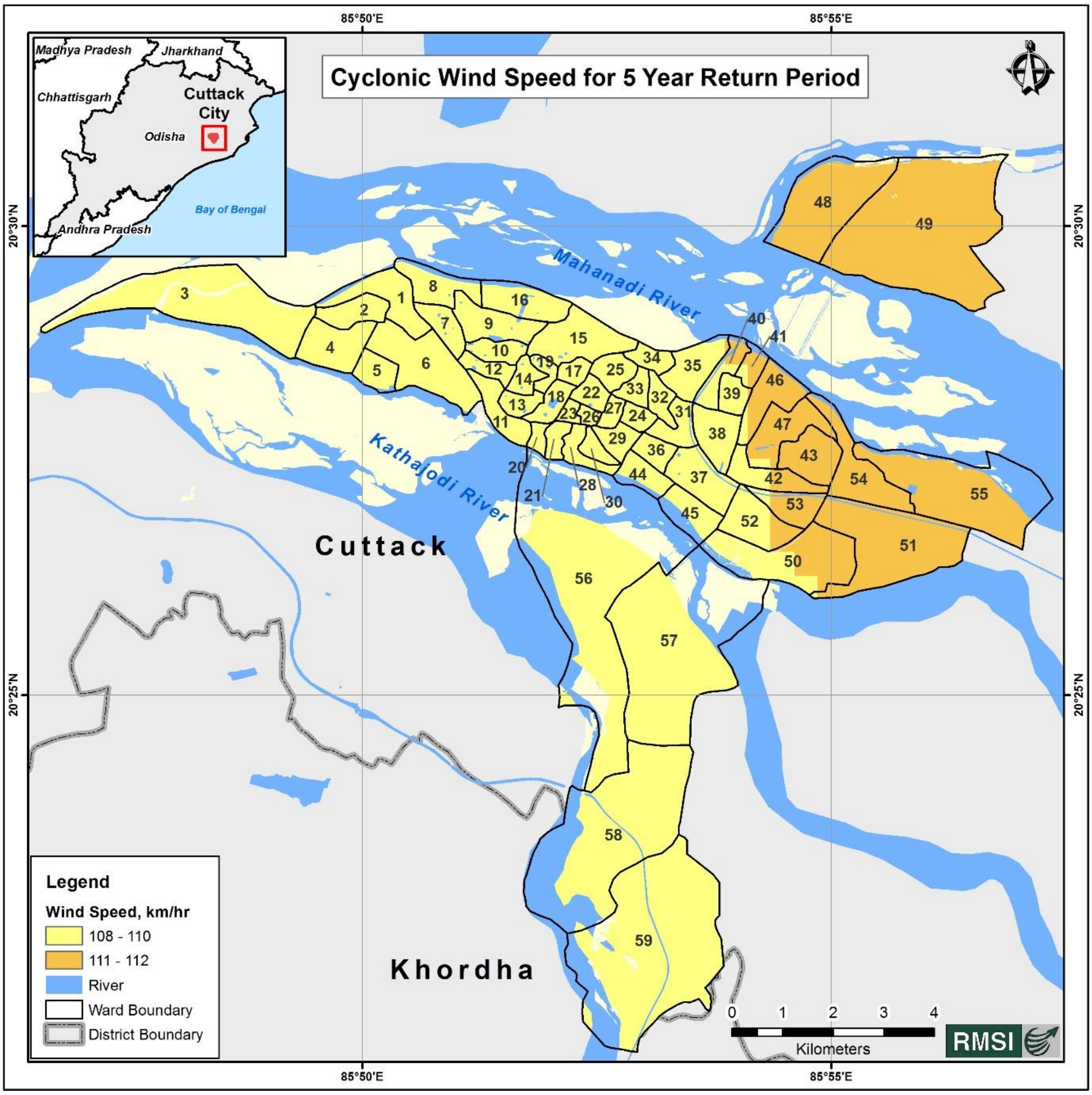


Figure 2-2 and Figure 2-3, and the maps for other scenarios, namely, 2, 10, 25, 50, 250, and 500-year return periods, are shown in Annex: 8.1.

The simulations for Cuttack city for 100-year return period in the normal scenario suggest that the wind speed varies from 204 km/h in the south to 213 km/h in the north. However, in the extreme scenario of 500 year-return period event, the range may vary from 253 km/h to 266 km/h.

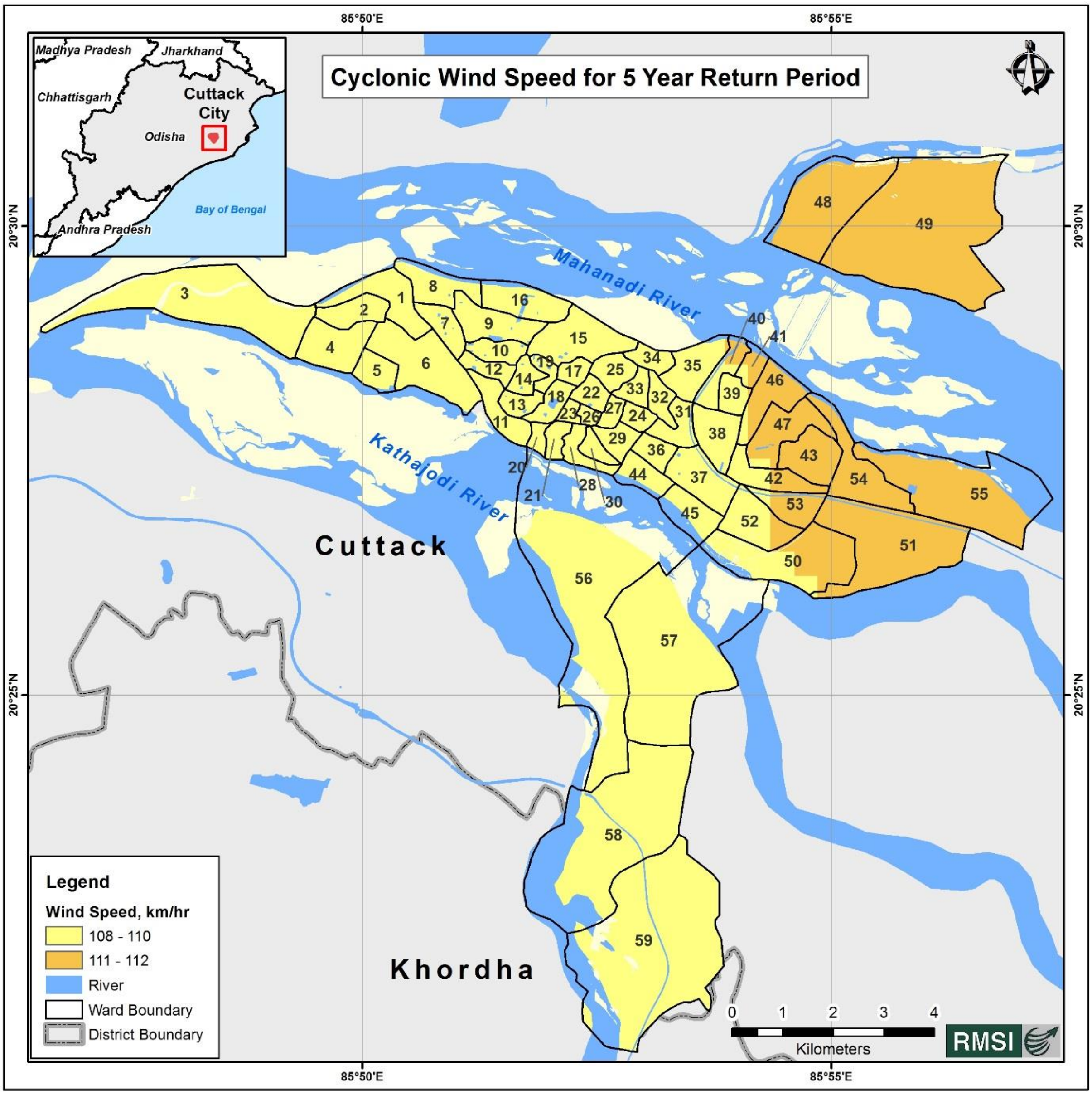


Figure 2-2: Wind hazard map for 5-year return period without climate change impact

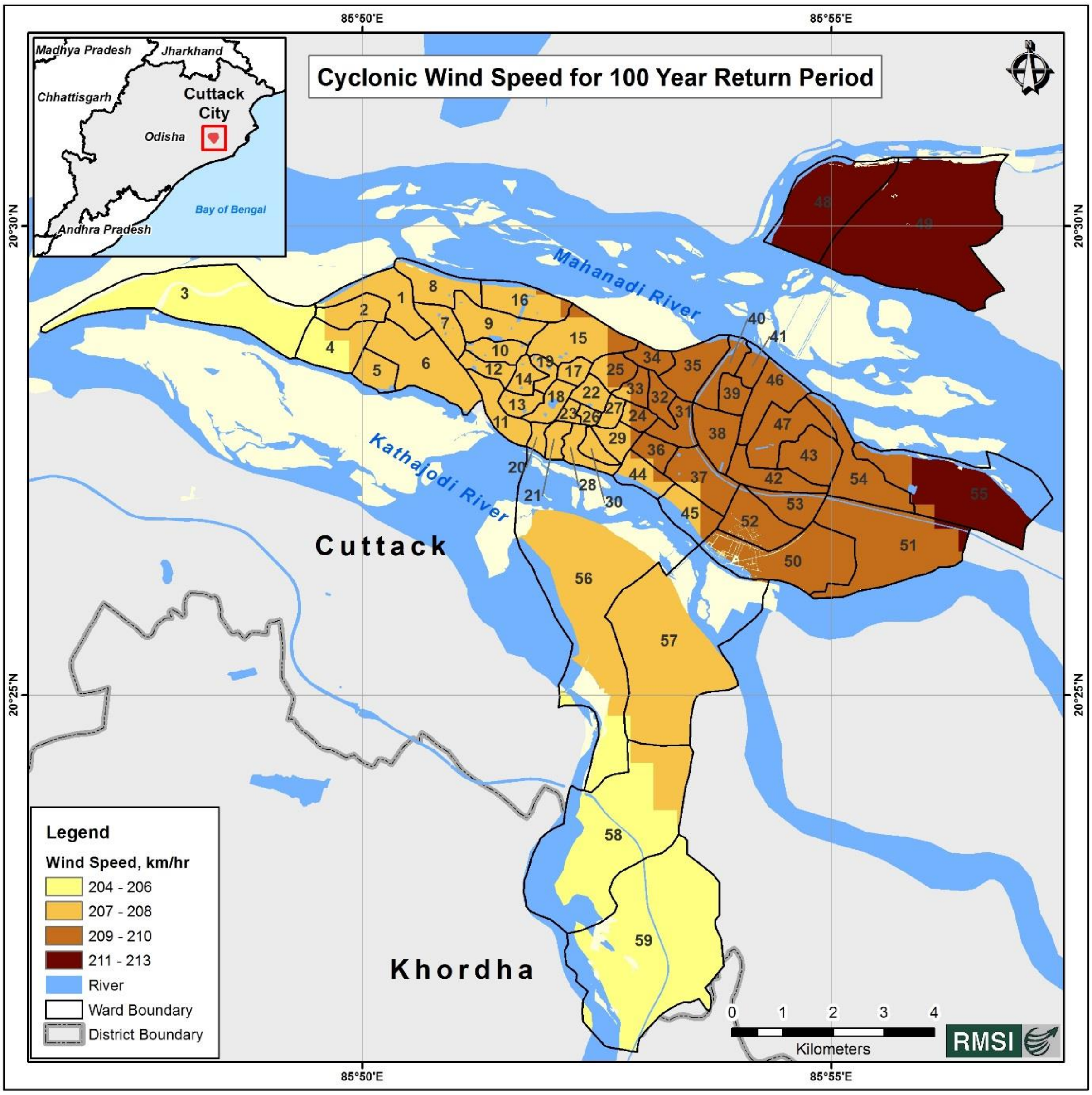


Figure 2-3: Wind hazard map for 100-year return period without climate change impact

2.2.2 WIND HAZARD MAPS WITH CLIMATE CHANGE IMPACT

The future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2-11% by 2100 (Knutson et al. 2010). In order to study the climate change scenario, the pressure drop is increased by 7% (an average value) and by 11% (extreme value) over the present historical events.

The wind hazard map for 100-year return period event with climate change impact of 7% and 11% are shown in Figure 2-4 and Figure 2-5 respectively. The other maps for 2, 5, 10, 25, 50, 250 and 500-year return period events with climate impact of 7% and 11% are shown in Annex: 8.1.

Analysis indicates that the city is likely to experience a minimum wind speed of 212 km/h in the south to 221 km/h in the north for 100 year-return period applying 7% climate change scenario. However, the corresponding values may rise to 215 km/h and 225 km/h respectively in the case of 11% climate change scenario.

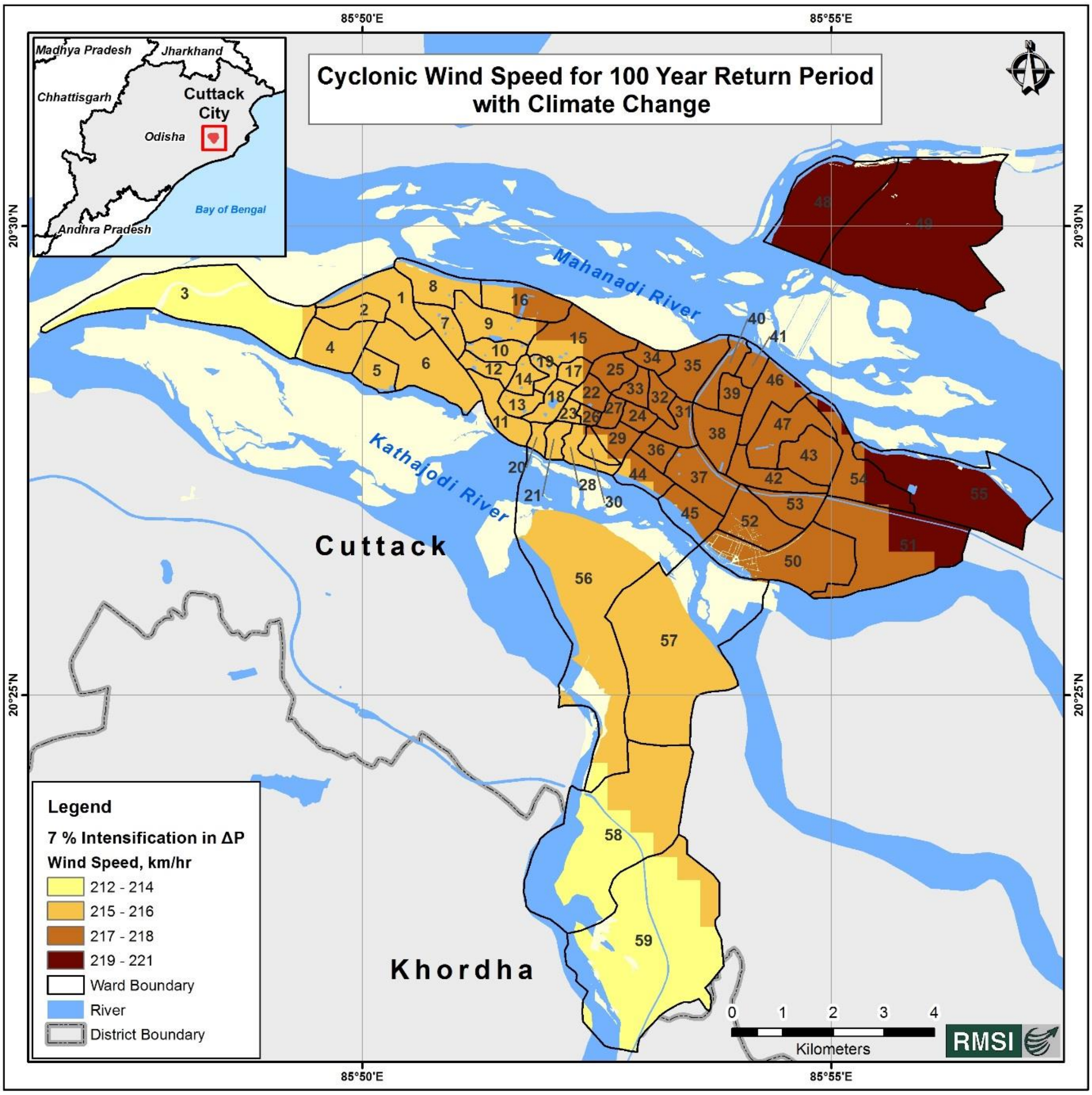


Figure 2-4: Wind hazard map for 100-year return period with climate change impact of 7%

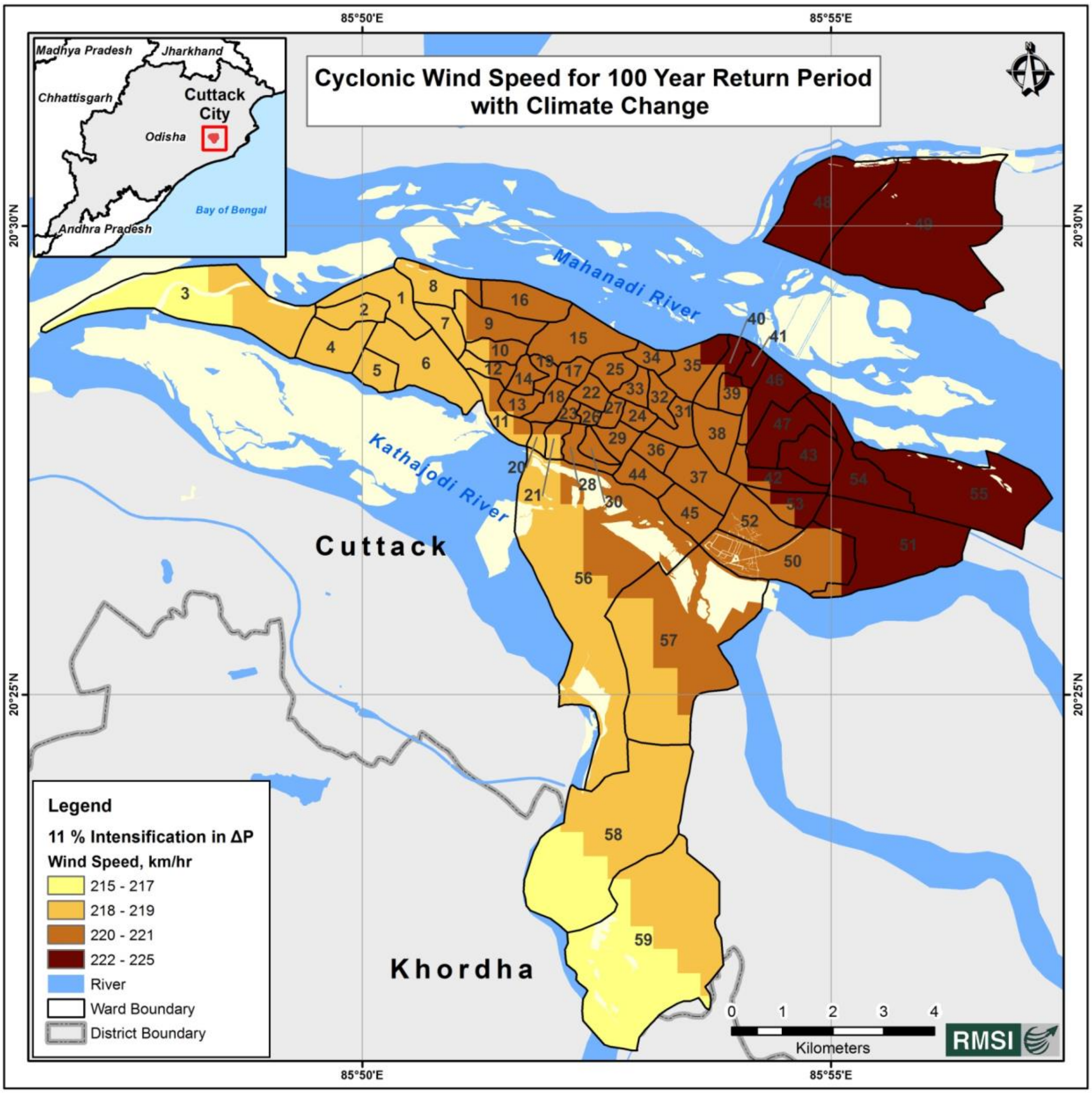


Figure 2-5: Wind hazard map for 100-year return period with climate change impact of 11%

2.3 Flood Hazard Assessment

2.3.1 Assessment of localized flooding due to flash flood/water logging

Ward No. 2, 3, 9, 14, 17, 20, 26, 33, 40, 43 (Figure 2-6) are especially prone to water logging due to the low-lying nature of the land and choked narrow drains. Inside the city, due to its topographical characteristics and disposal of solid waste materials in the drain, storm water drains are choked and cause water logging problems even during light rains.

The problem becomes serious when flood water levels in the two major rivers are above the water levels in the drainage channels and the pumping capacity is not sufficient to pump out the water. Water logging conditions cause serious public health and safety problems for the city residents.

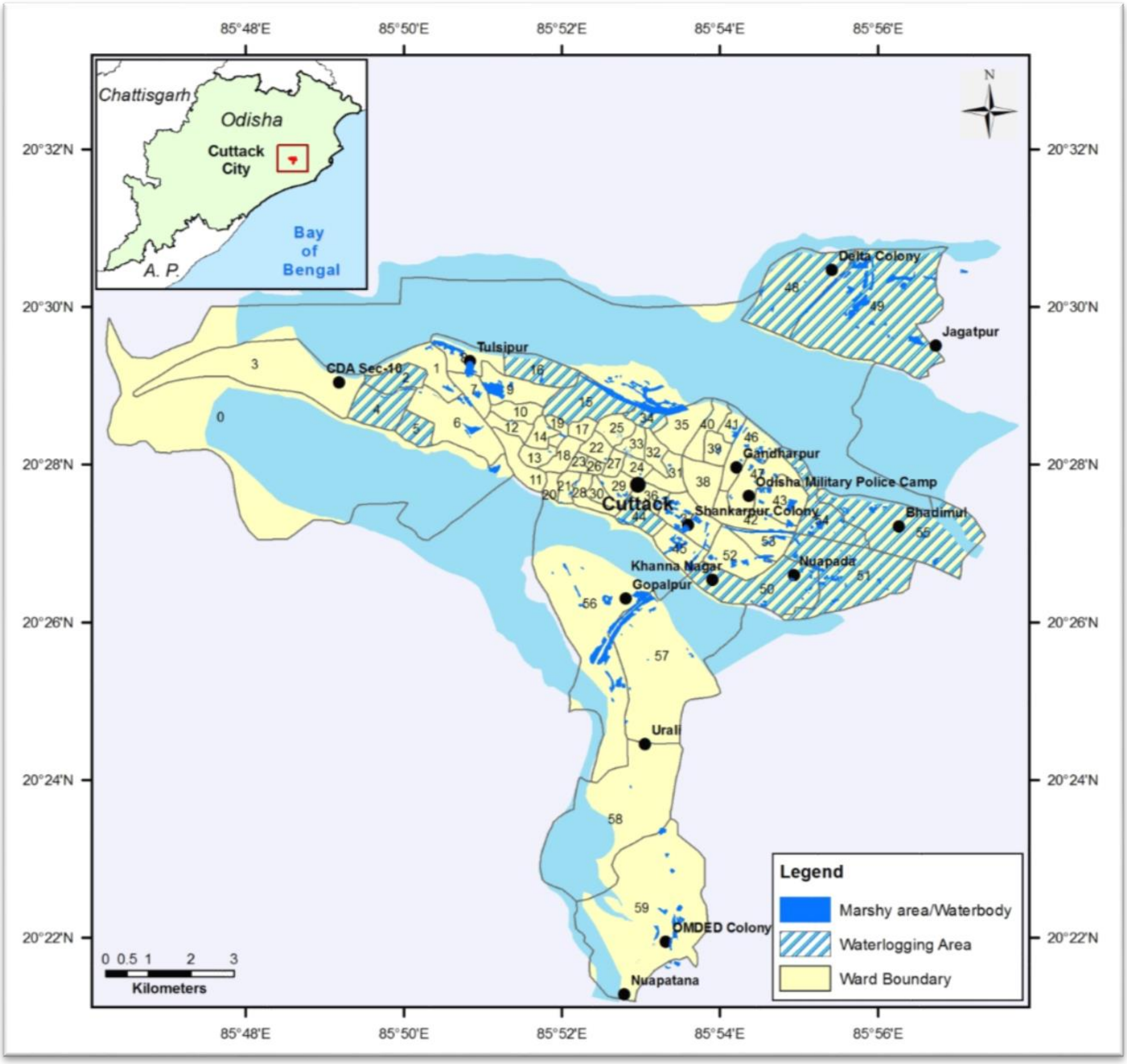


Figure 2-6: Localities affected due to water logging during the recent past, Cuttack city

2.3.2 FLOOD HAZARD MAPPING UNDER CURRENT CLIMATIC CONDITIONS

The boundaries of flood hazard scenarios were determined using two-dimensional hydraulic modeling. Flood extent maps have been prepared by integrating model results with GIS data to produce maps with varying flood depths. The maps show the flood extents and flood water depths for various return periods. The flood hazard map for 5-year return period is shown in Figure 2-7, while flood hazard maps for other return periods are given in Annexure 8.1.2.

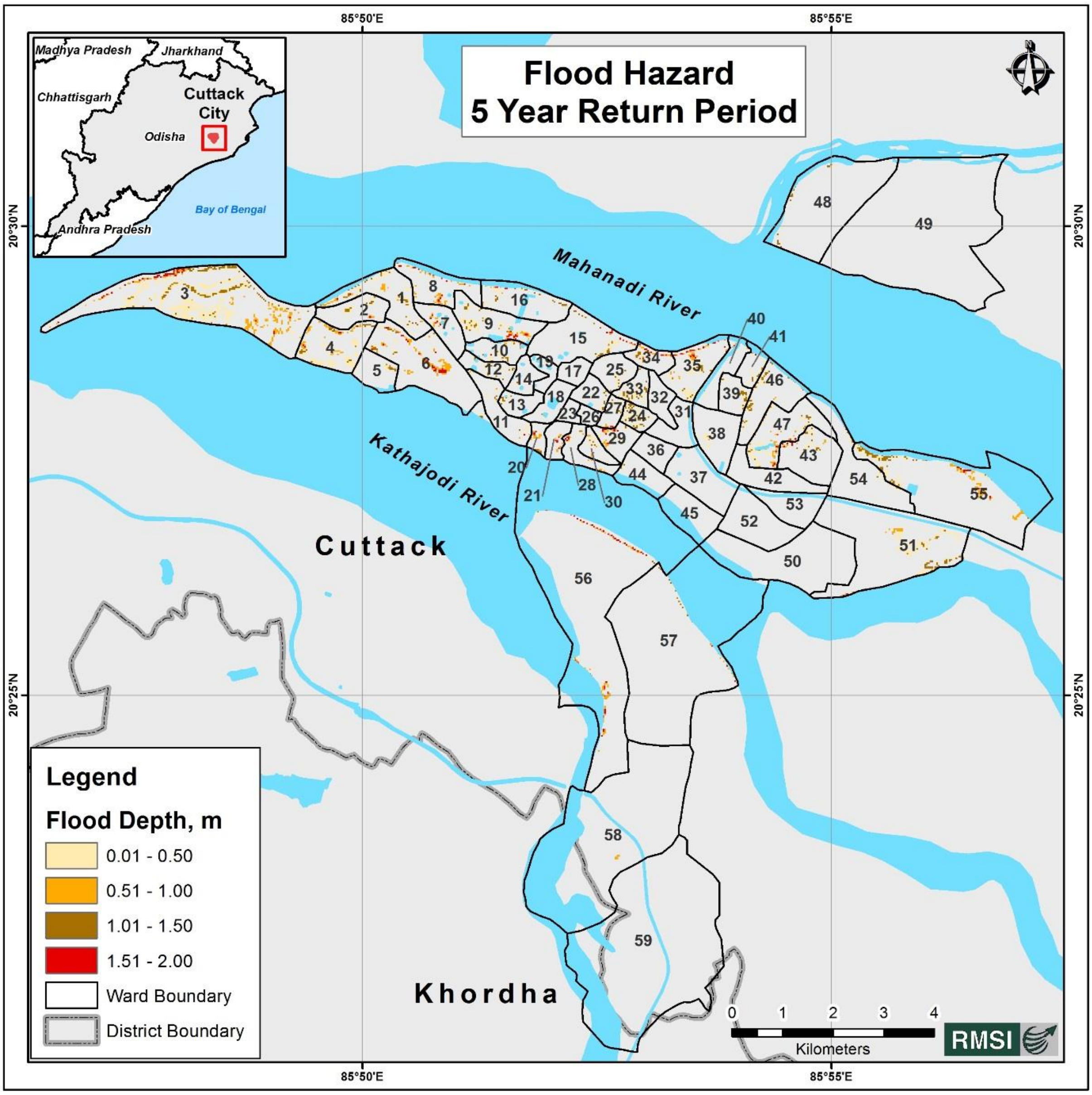


Figure 2-7: Flood Hazard Map for 5-year return period

The flood hazard assessment shows the following:

- Ward numbers 2, 4, 9, 20, 24, 27, 30, 33, 35, 39, 41, and 42 are flood prone wards in the city mostly affected due to localized flooding. At least 10% areas of these wards are prone to flooding even in low return period events (2-year return period). However, as one moves from low to high frequency flooding, a greater number of wards get affected. For a 100-year return period flood events, almost all the wards get affected. On an average, 23% area of each ward would get affected due to flooding for such an event. For detailed ward wise inundation for various return period flood are provided in Annexure 8.1.2
- In terms of flood depth, average depth of flooding varies from 0.50m to 1.00m for lower return periods in most of the wards. However, some wards show higher values due to proximity to the riverbank or the main city drains. In addition, average depth of flooding can be higher in some wards due to the presence of localized low-lying areas. For a 100-year return period event, the average depth of flooding varies from 1.20m to 2.0m in several wards (Figure 8-39).
- The maps show that flood extents are not only limited to areas near the riverbanks but are also spread to low-lying areas and areas near drain outlets. In lower return periods,

floodwater remains in isolated patches. However, in higher return period floods (more severe cases) flood depths and extents start increasing rapidly and cover larger areas of the city.

- It is clearly visible from the flood hazard maps across all return periods that the city is not significantly affected due to flooding in the Mahanadi River because it is very well protected by embankments. However, there are some locations where houses have been constructed between the embankment and the river, making them highly vulnerable to riverine flooding.
- In the last 50 years, the discharge in the Mahanadi River has exceeded 44,000 cumecs only twice in 1982 and 2008. The floods in these two years correspond to 50-year return period flood events. It can also be inferred that the embankments surrounding the city areas are very well design for flood events up to 50-year return period.
- Ward No. 6, 9, 15, 19, 24, 27, 32, and 33 are highly prone to localized flooding because of the low lying areas in these wards.
- There are many water storage ponds in the City, which are silted and the water holding capacity of these ponds has been decreased drastically. If these ponds and water storing structures are desilted and maintained well, they can help control localized flooding. In addition to the existing ponds and storing structure, there are many natural low-lying areas, which can be developed properly for water storing purposes during flooding. These low-lying areas are in Masik Patna Colony, Srivihar Colony, Police Colony, Kafla Colony, Chotti Masjid Area, Siba Bajar, Chhatara Bajar Pond, and Shankarpur Colony.

2.3.3 FLOOD HAZARD MAPPING UNDER PROJECTED FUTURE CLIMATIC CONDITIONS

In order to understand the possible impact of climate change on flood hazard, changes in rainfall and discharge patterns in the climate change scenarios was analyzed. The analysis shows that annual average rainfall changes for the three time slices considered for the study are estimated to 1.65%, 6.25%, and 9.65% (For monsoon period) from the current climatic conditions. From these three climatic change scenarios, only scenarios 1 (6.25% change) and scenario 2 (9.65% change) show some significant changes in future climatic conditions. Information from two climate change scenarios has been incorporated to the historical rainfall/flows to carry out flood frequency analysis. The Gumbel Extreme Value Distribution method is used for design flows estimation under the future climate conditions. For the flood inundation modeling under future climate conditions, three return periods of 25, 50 and 100 years of flows are considered. Figure 2-8 shows 100-year return period scenario under the future climatic conditions for climate change scenario 1 (6.25%).

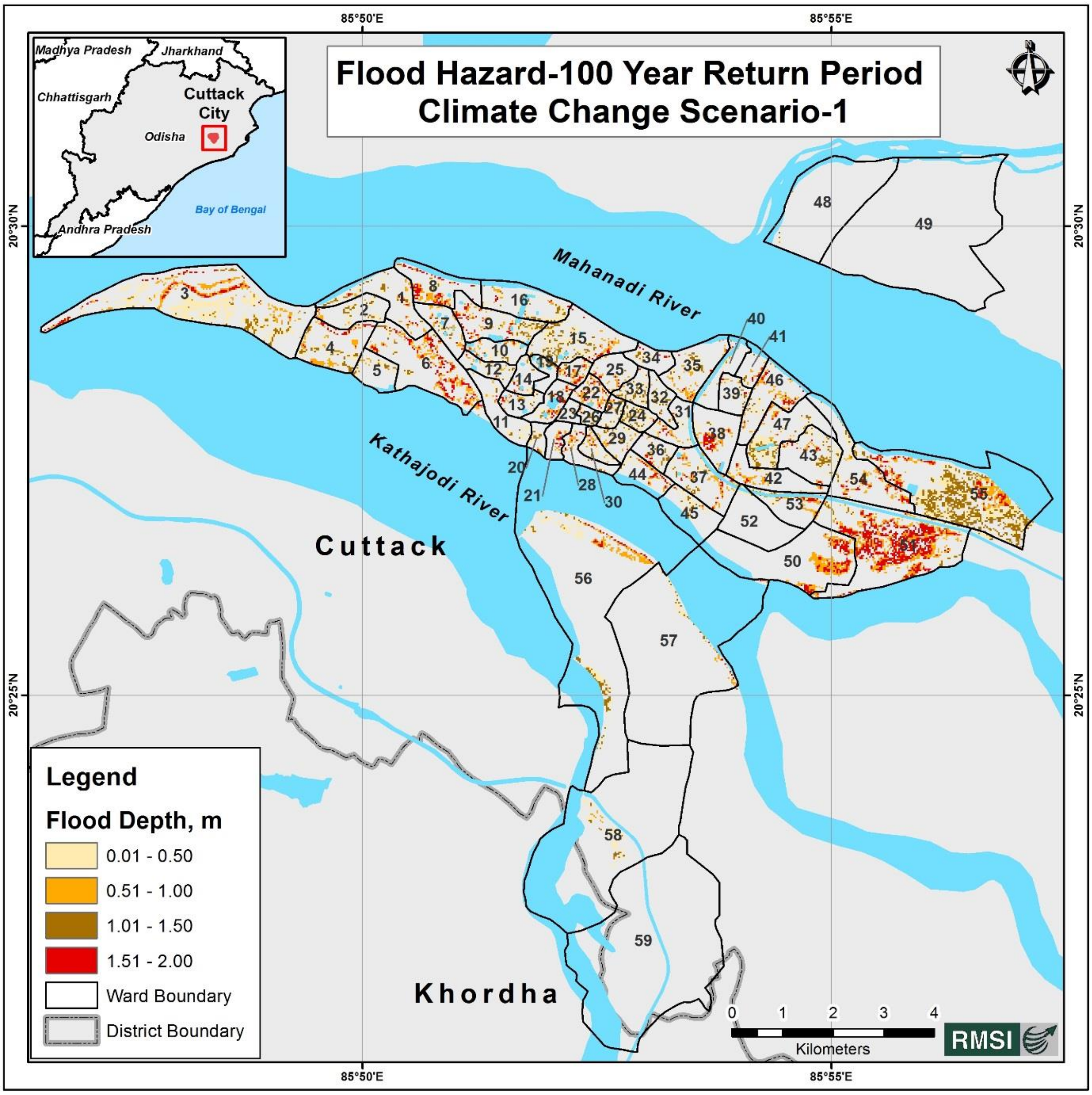


Figure 2-8: Flood Hazard Map for 100-year return period with climate change scenario-1

2.4 Heat Waves and Urban Heat Islands

Cuttack district has been experiencing scorching summers and heat-associated deaths reported was highest in 2005. The death in the city was very low. Extremely high increase in average monthly mean maximum temperatures, continuous increase in the number of hot days, and a rising temperature difference between Cuttack and the other nearby cities gives the impression that the city is gradually emerging as an urban heat island.

2.4.1 ANALYSIS RESULTS

In Cuttack city, the annual mean surface air temperature has risen during the past two centuries. However, the rate of increasing trend has sharply increased in the last few decades of the 20th century, which could be attributed to global climate change due to anthropogenic forcings. Further analysis of data also suggests that the rate of increase in temperature is found to peak in May and June months of the year. In the year 1998, the entire state of Odisha faced an unprecedented heat wave situation, because of which 2,042 persons lost their lives. Though extensive awareness campaigns have largely reduced the number of casualties during the post-1998 period, a good number of casualties are still reported each year. In the year 2009, Odisha experienced the worst heat wave since the one in 1998. The heat wave killed more than 2,000 people, of which 1,500 died in coastal Odisha alone.

The temporal analysis of daily temperature data in Cuttack for the past three decades has shown a steady increase in the city temperature over the years. In fact, Cuttack has become one of the hottest Indian cities in the recent times. Extremely high increase in annual average maximum temperatures, continuous increase in the number of hot days, and rising temperature difference between Cuttack and the nearby cities gives the impression that the city is gradually emerging as an urban heat island. During May 2013, the maximum temperature of 44.5ºC was recorded at Cuttack. Subsequently, heat stress conditions prevailed in Cuttack throughout May 2013. Most of the districts in Odisha, on an average, recorded 40ºC during April 2014 and the temperature across a few districts in coastal Odisha reached 46ºC by the end of May. Very severe heat stress conditions prevailed in May / June that year. The increasing trends have been reported in observed maximum (daytime high) and minimum (nighttime low) surface temperature at Cuttack during the past 50 years. It is also noticed that the rate of increase in daytime maximum temperature at Cuttack is higher in comparison to the nighttime minimum temperatures meaning thereby that the diurnal temperature range (DTR) at this site is increasing in recent decades.

Physical considerations indicate that tropospheric warming due to observed rate of temperature rise should lead to an enhancement of moisture content in the atmosphere, which is associated with an increase in heavy rainfall events. Therefore, even though an overall decrease in annual mean rainfall anomalies has been monitored at Cuttack, more frequent incidences of high intensity rainfall could be expected in coming years and decades. Extreme rainfall events should result in, flash floods, and crop damage that would have major impacts on society, the economy, and the environment.

2.5 Earthquake Hazard Assessment

2.5.1 Seismotectonics of the area around Cuttack

Several faults have been identified in the region around Cuttack and some have shown evidence of movement during the Holocene epoch (SEISAT, 2000). The Brahmani Fault near Bonaigarh is one among them (SEISAT, 2000). The Mahanadi River also flows through a graben structure. As per Seismotectonic Atlas of India (SEISAT, 2000), several deep-seated faults are situated beneath the Mahanadi delta.

The Mahanadi and Brahmani graven, Mahanadi delta, and parts of Balasore and Mayurbhanj districts come under earthquake risk zone –III (moderate damage risk zone) as per the earthquake risk zonation map prepared by Bureau of Indian Standards and published by Building Material Technology Promotion Council of India (BMTPC, 2006).

The following figure presents the Seismotectonic map of the areas in and around Cuttack.

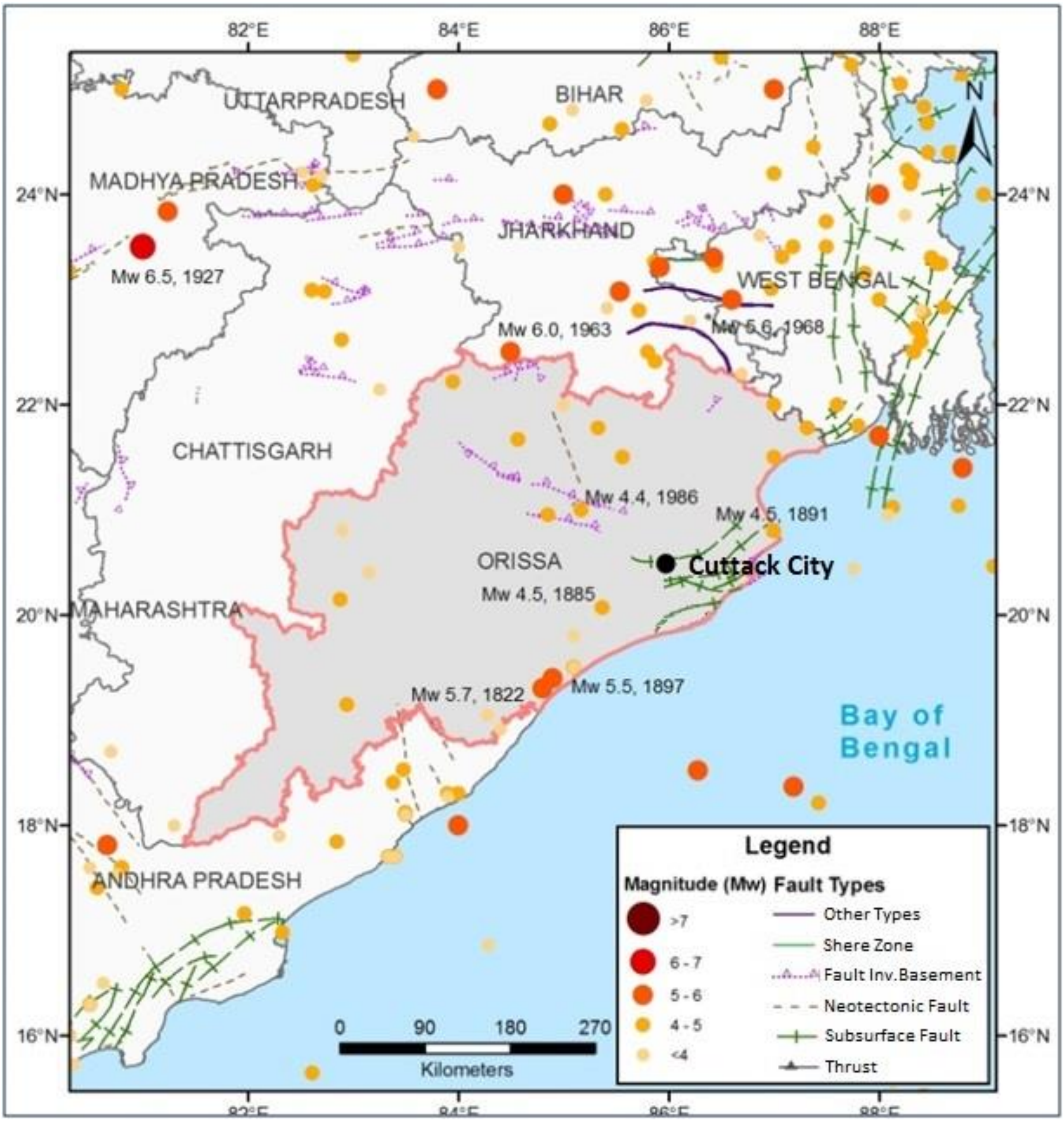


Figure 2-9: Seismotectonic map of areas around Cuttack

2.5.2 Seismic hazard at rock level

The Global Seismic Hazard Analysis Program (GSHAP; www.seismo.ethz.ch/gshap/), provides probabilistic seismic hazard values in and near Cuttack city of about 0.13 g corresponding to 10% probability of exceedance in 50 years (475 years return period) at base rock level. This clearly indicates that PGA values are almost the same for the entire city, while, in reality, different parts experience different levels of ground motion due to local soil condition effects.

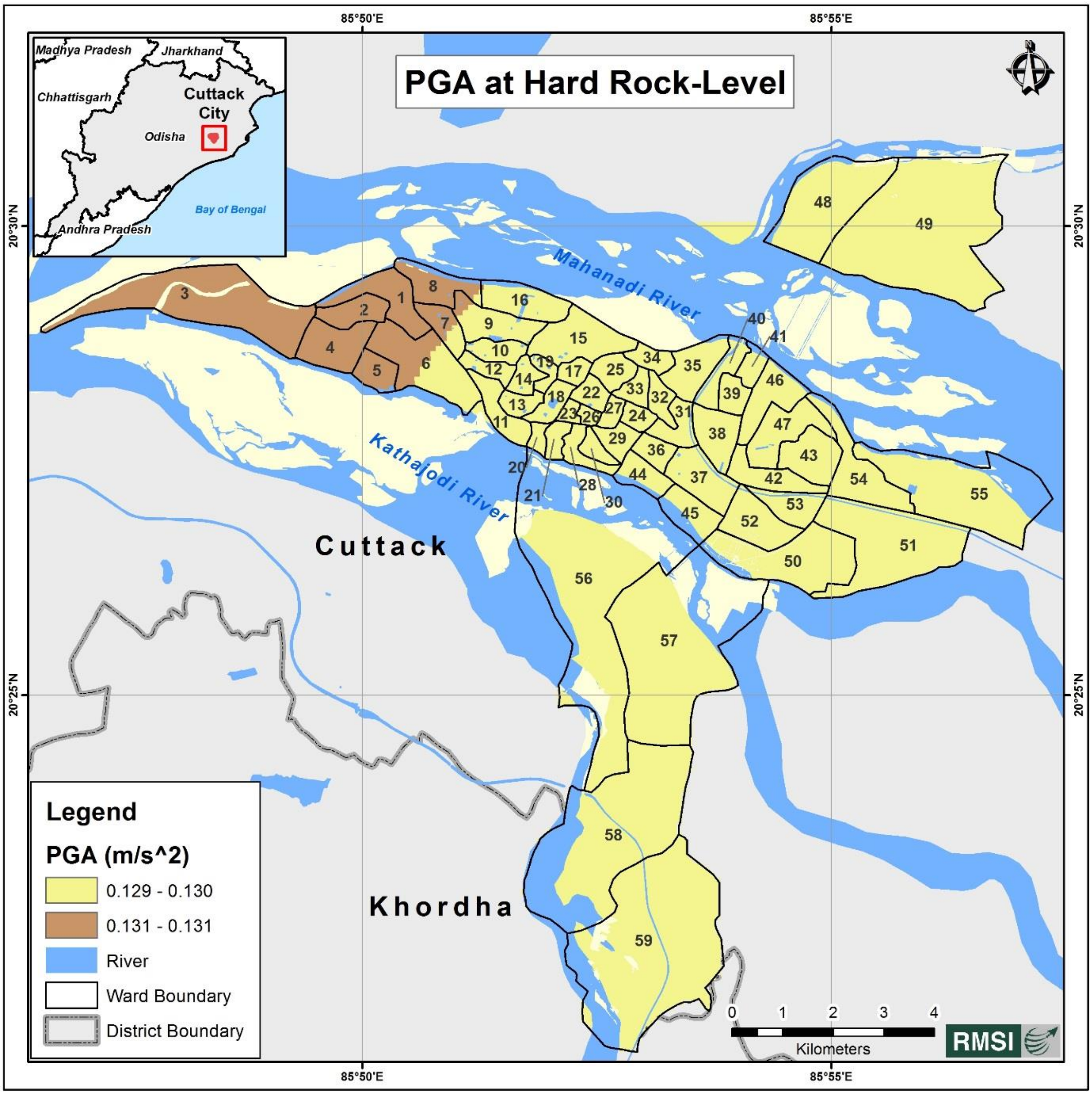


Figure 2-10: Ward level PGA map of Cuttack city at hard rock-level (after GSHAP)

2.5.3 MODELING SOIL AMPLIFICATION

Local soil conditions can significantly affect earthquake ground motion of an earthquake. The soil top layer act as filters that can modify the ground motion as a function of their dynamic characteristics. Soft, weak soils tend to amplify long-period seismic motions and thus generally impart large ground displacements to structures, while very stiff soil and rock tend to de-amplify the ground motion.

For dynamic purposes, soils are classified in terms of their shear wave velocity. A majority of authors, including the European and NGA developers (for example, Schott et al., 2004; Campbell et al., 2009; Boore et al., 2011; Sandikkaya et al., 2013) have used the average shear-wave velocity in the upper 30 meters of sediments, Vs30, as the parameter for characterizing effects of sediment stiffness on ground motions. Use of this parameter is considered to be diagnostic in determining site amplification than the broad and ambiguous soil and rock categories used in earlier studies with the exception of the relation of Boore et al. (1997), who used Vs30. Therefore, the site amplifications of ground motions relative to a reference rock condition are continuous functions of Vs30 and have been used for the city, due to the absence of Cuttack-specific relationships between site classes and amplification effects, and coarse geology at 1:250,000 scale. The widely used NEHRP's site amplification procedure based on shear wave velocities (Wills et al, 2000, BSSC, 2001) has been applied in this study (Table 2-2).

Table 2-2: Soil Classification Scheme based on Shear Wave Velocities

Soil Index value	NEHRP /CDMG Class	Brief Description	Shear Wave Velocity (Vs,30) m/s
1.0	B	Very hard to firm rocks mostly metamorphic and igneous rocks	>760
1.5	BC	Firm sedimentary rocks (mid Miocene age) and weathered metamorphic	555-1000
2	C	Sedimentary Formation Mid-Lower Pleistocene age	360-760
2.5	CD	Weak rock to gravelly soils - Deeply weathered and highly fractured bedrock	270-555
3.0	D	Holocene Alluvial soils	180-360
3.5	DE	Young alluvium / Water-saturated alluvial deposits	90-270
4.0	E	Non-engineered artificial fill, soft clays, peat and swamp deposits	<180

Using Wald et al. (2004) and Wald and Allen (BSSA, 2007) approach, gridded (0.1 km x 0.1 km) Vs30 map and corresponding soil-index map have been generated using NEHRP (Figure 2-11) classification.

The site–dependent amplification factors followed the non-linear two-dimensional soil amplification factors modified from Choi and Stewart (2005); and Walling, M, Walter Silva, and Norman Abrahamson (2008), which relate non-linear multipliers based on the level of ground motion (PGA) and averaged soil index assigned for a given location.

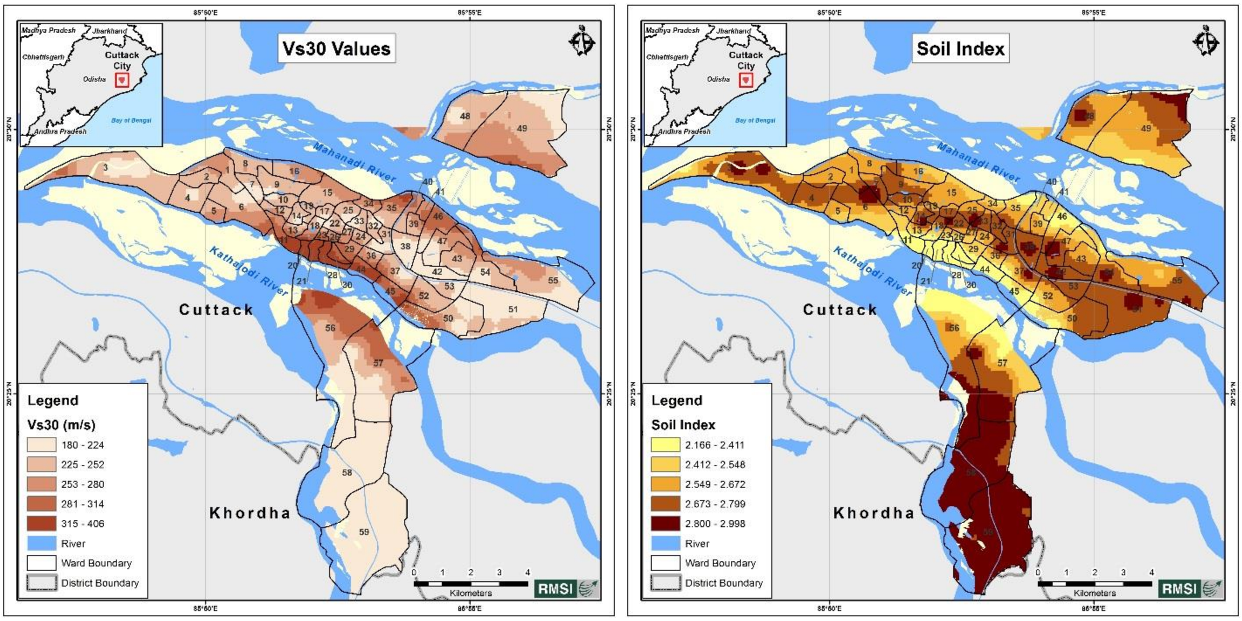


Figure 2-11: Spatial variation of (a) Vs30 values and (b) Soil-Index for Cuttack city

The plot of amplification factors for different soil index classes (corresponding to respective Vs30 values) normalized by the amplification for reference BC soil Vs30=760 m/s (soil index 1.5), used in the study is shown in Figure 2-12.

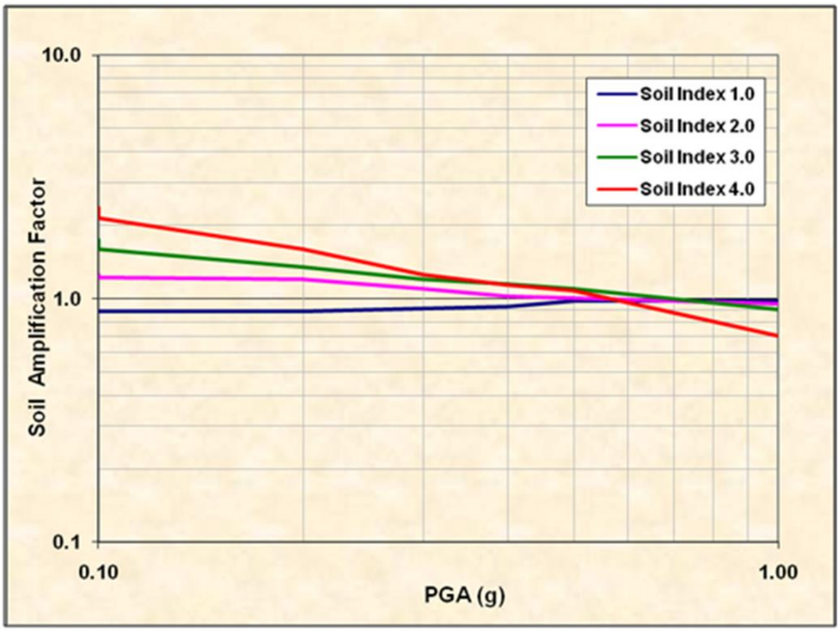


Figure 2-12: Site Amplification Factors for different Soil Index Values (=Vs30 Values)

The site amplification factors were then calculated based on the high resolution Vs30 based soil index map, and these have been multiplied with the PGA Rock values derived (as given in Figure 2-11b) for the city.

The final seismic hazard map generated at ward level contains seismic ground motion estimates at surface level, by taking into account the local soil-amplification factors in different parts of Cuttack city (Figure 2-13).

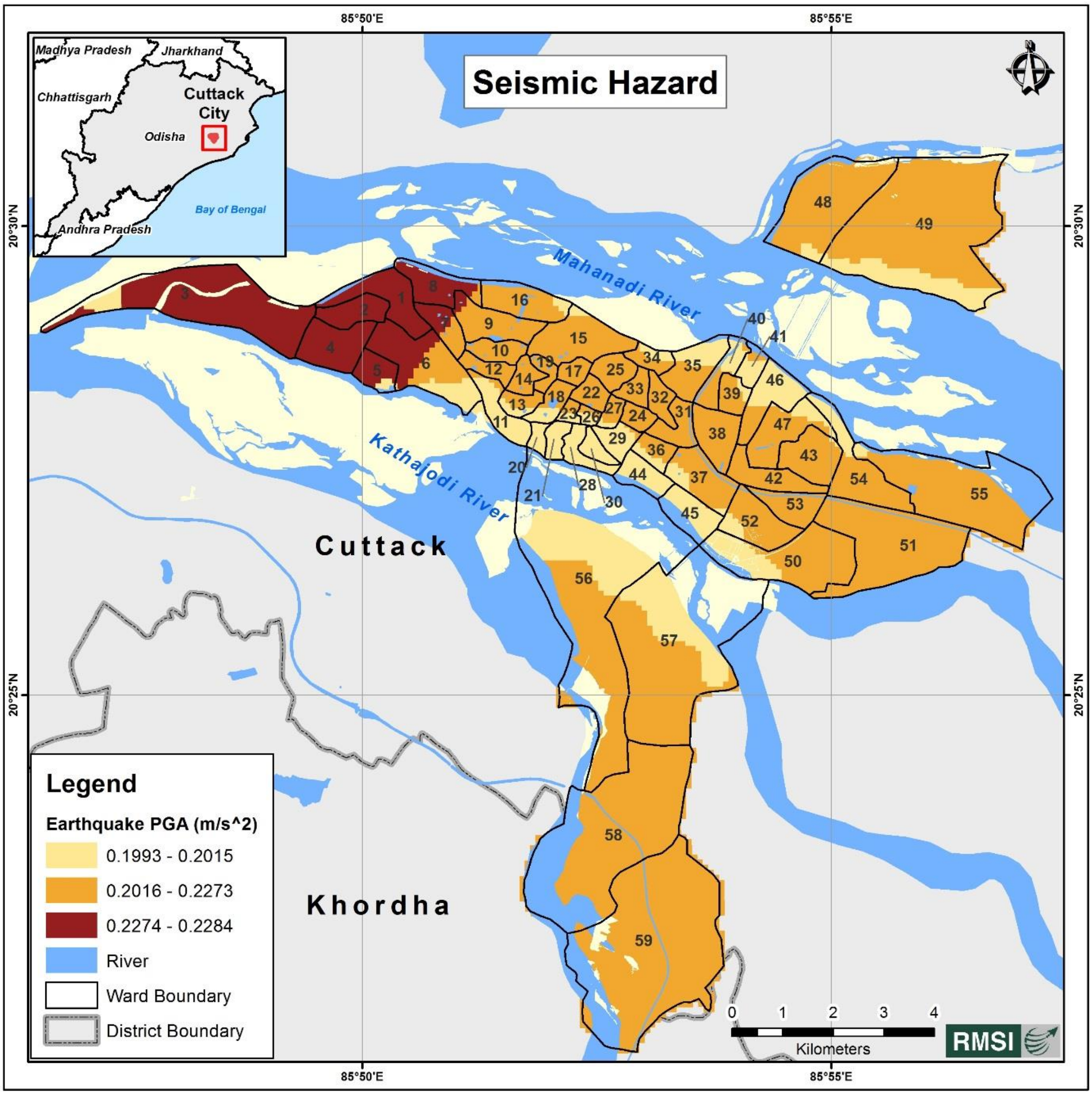


Figure 2-13: Ward level PGA based Probabilistic Seismic Hazard Map for 10% Probability of exceedance in 50 Years (475-Year Return Period) for Cuttack city

As discussed earlier, from Figure 2-13 it is clear that different parts of the city are expected to experience different levels of ground motion due to local soil amplification.

2.6 Urban Fire Hazard Analysis for Cuttack City

The high-density population, traditional houses, and high temperatures in summer months provide favorable conditions for fire accidents. The City has three fire stations, all located in the central island (Figure 2-14). The narrow roads can make the operation challenging in case of fire incidents.

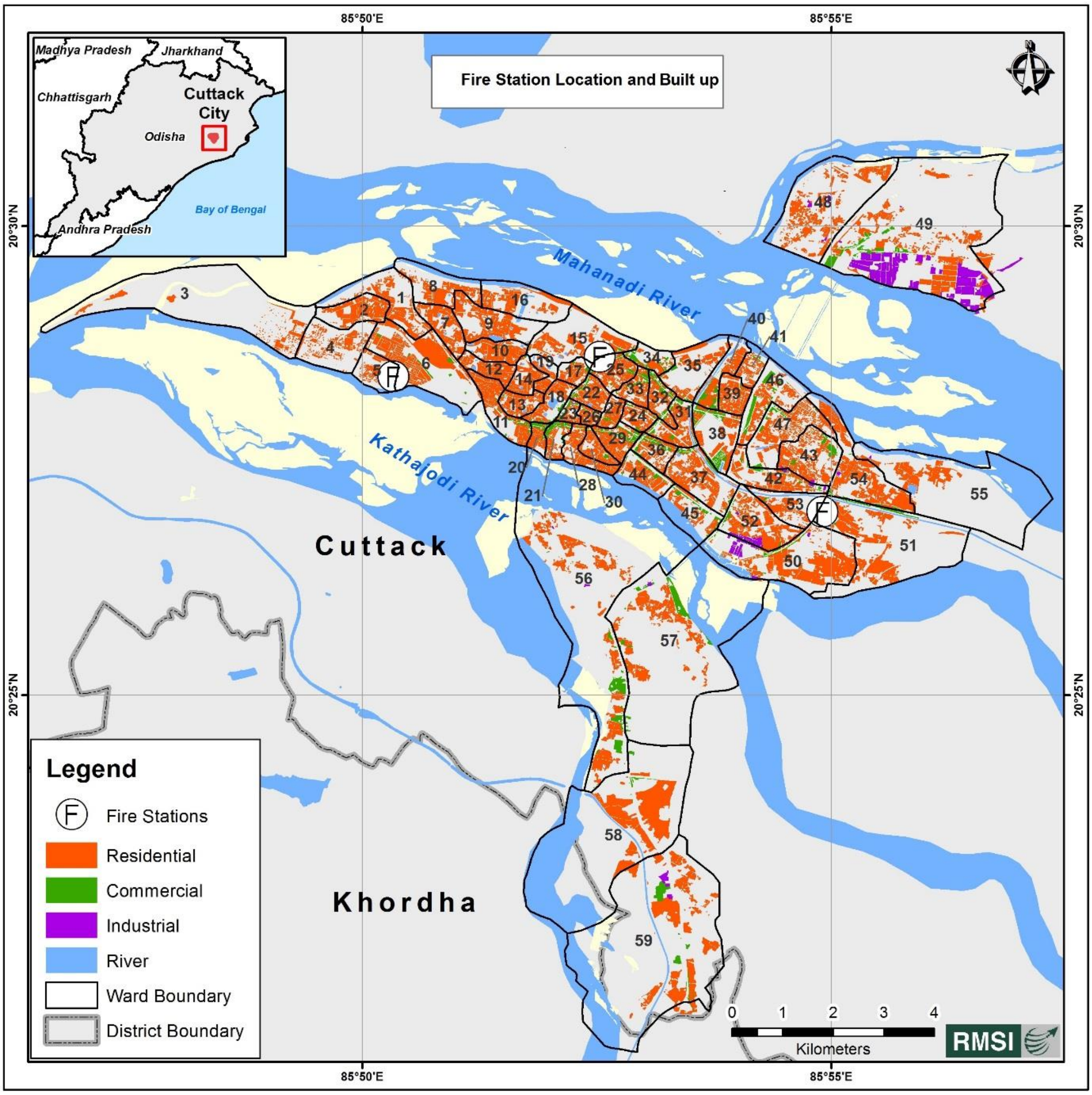
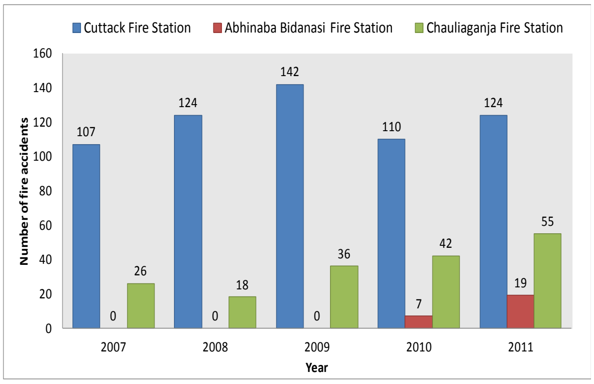


Figure 2-14: Location of fire station in Cuttack city

2.6.1 URBAN FIRE HAZARD ANALYSIS

Historical event data (Figure 2-15) shows that the occurrence of fire is higher in residential buildings compared to commercial and industrial buildings. More events are reported in Cuttack fire station compared to the rest to the fire stations. The Cuttack fire station is located in the most densely populated area, which has a high density of residential, and commercial buildings.



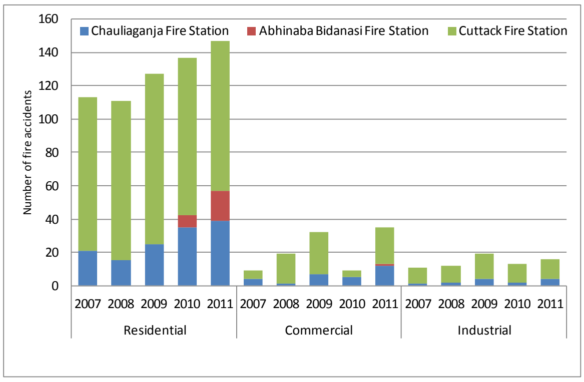


Figure 2-15: Fire accidents – station wise and building type wise

The market areas of Cuttack city are characterized by narrow roads and most of the buildings have basements that are used as godowns or offices, which are more vulnerable to fire hazard risks. Fire safety drills and installation of fire alarms are not available in these traditional markets. The only precaution available is having fire insurance, which acts as a safety net in case of an event and mostly for medium to big commercial establishments only.

2.7 Climate Modeling and Analysis of Extreme Weather Events

Climate change data analysis for inferring projections of future climate change for Cuttack has been undertaken on four time scales. These time slices are baseline (1961-1990), near term (2020s i.e., 2010 to 2039), medium term (2050s i.e., 2040 to 2069), and long term (2080s i.e., 2070 to 2099). A set of core climatic indicators (*https://www.ncdc.noaa.gov/indicators/*) have also been calculated from the bias corrected datasets for baseline and future time slices at each model grid-point before averaging over the total grid points within the region of interest (Cuttack). The focus is to infer vital information required for city-level decision-making in developing disaster management strategies and structuring future development plans in relevant sectors.

Table 2-3 provides a snapshot of annual and seasonal means of projected warming area averaged over Cuttack at the three selected time slices with respect to the baseline. Mean annual temperatures are projected to increase by 1.27°C by the 2020s, 2.77°C by the 2050s and 4.56°C by the 2080s. The projected average warming in Cuttack by the middle of this century and beyond is projected to be marginally higher during winter than during the pre-monsoon, monsoon or post-monsoon seasons. This is similar to IPCC findings that future warming at Cuttack is likely to be most pronounced in winters.

Table 2-3: Projected warming area averaged over Cuttack District at three time slices

Average surface air temperature change (deg C)	ΔT, 2020s	ΔT, 2050s	ΔT, 2080s
Annual Mean	1.27	2.77	4.56
Winter (Jan-Feb)	1.38	2.92	5.10
Pre-monsoon (Mar-May)	1.43	2.87	4.81
Monsoon (Jun-Sep)	1.05	2.53	4.13
Post-monsoon (Oct-Dec)	1.32	2.90	4.54

Table 2-4: Projected rise in maximum surface air temperature area-averaged over Cuttack at three time slices

Mean maximum surface air temperature change (deg C)	∆T max, 2020s	∆T max, 2050s	∆T max, 2080s
Annual	1.16	2.68	4.46
Winter (Jan-Feb)	1.25	2.72	4.91
Pre-monsoon (Mar-May)	1.32	2.71	4.63
Monsoon (Jun-Sep)	0.99	2.54	4.13
Post-monsoon (Oct-Dec)	1.18	2.79	4.44

Table 2-5: Projected rise in minimum surface air temperature area-averaged over Cuttack District at three time slices

Mean minimum surface air temperature change (deg C)	∆T min, 2020s	∆T min, 2050s	∆T min, 2080s
Annual	1.37	2.87	4.67
Winter (Jan-Feb)	1.51	3.13	5.30
Pre-monsoon (Mar-May)	1.54	3.02	5.00
Monsoon (Jun-Sep)	1.12	2.52	4.12
Post-monsoon (Oct-Dec)	1.46	3.02	4.65

Table 2-4 and Table 2-5 above provide the seasonal and annual means of projected rise in maximum daytime and minimum nighttime surface air temperatures area-averaged over Cuttack at three time slices respectively. It is interesting to note here that projected rise in nighttime minimum temperature is more than projected day time maximum temperature at all time-slices meaning thereby that the diurnal temperature range (DTR) at Cuttack should be smaller in future. The decline in DTR and rise in surface temperature is projected to be highest during pre-monsoon season implying that thermal stress and discomfort to the population would be most pronounced in the pre-monsoon hot summer season.

The seasonal and annual changes in precipitation projected over Cuttack at the three future time slices are summarized in Table 2-6. On an annual mean basis, the projected change in precipitation over the district is a decline in rainfall by about 0.3% of the baseline value around 2020s, but an increase by 3% of the baseline value around 2050s and by 7% of the baseline value around 2080s. Within the four seasons, the model results suggest a modest increase in rainfall of about 9% during southwest monsoon (June to September). The temperature water vapor feedback at higher warming should induce more pronounced convective instabilities, which should lead to an increase in precipitation during mid-21st century and beyond. A decline in pre-monsoon and post monsoon season rainfall is projected at all time scale for the future. A significant decline of as much as 15% may be expected in post-monsoon season rainfall by the end of this century. On monthly basis, April and December are likely to be the two months when rainfall could be expected to decline substantially throughout during this century.

Table 2-6: Projected change in area-averaged precipitation (ΔP, percent change) over Cuttack District at three time slices

Season / Annual Mean	Ensemble rainfall percent departure, 2020s (2010-2039)	Ensemble rainfall percent departure, 2050s (2040-2069)	Ensemble rainfall percent departure, 2080s (2070-2099)
Annual	-0.31	3.04	7.22
Winter (Jan-Feb)	1.47	-4.16	-5.60
Pre-monsoon (Mar-May)	-5.95	-8.81	-10.65
Monsoon (Jun-Sep)	1.65	6.25	9.65

Season / Annual Mean	Ensemble rainfall percent departure, 2020s (2010-2039)	Ensemble rainfall percent departure, 2050s (2040-2069)	Ensemble rainfall percent departure, 2080s (2070-2099)
Post-monsoon (Oct-Dec)	-6.77	-9.43	-15.15

In the following sub-sections, we shall present and discuss the key findings on the implications of the projected changes in temperature and rainfall over Cuttack together with likely changes in selected core climatic indicators based on our analysis for Cuttack district.

2.7.1 Projected Changes in Number of Hot Days / Warm Nights and Heat Wave Severity

With the projected annual mean warming of about 4.56°C by the end of this century over Cuttack, increases in the number of hot days (T_{max} > 90th percentile) and warmer nights are expected. The projected annual and seasonal mean changes in number of hot days over Cuttack are provided in Table 2-7. On an annual mean basis, the total count of hotter days is expected to increase on an average by about 12 over Cuttack by the end of this century. During pre-monsoon season, the peak in number of days with hotter daytime surface air temperatures is projected at all time-slices. This could be attributed to rise in daytime temperature with time such that day temperature becomes pronounced. This results in higher numbers in 90th percentile and is reflected in more number of hot days during the pre-monsoon season. There are significant changes in the number of hotter days over Cuttack during winter and post-monsoon seasons also, particularly during mid-century of beyond.

Table 2-7: Projected changes in area averaged increases in number of hot days over Cuttack district with respect to baseline at different time scales

Time Period	Average number of hot days (Tmax > 90th percentile)	Average increase in number of hot days (Tmax > 90th percentile)		
	Hot days in Baseline	Hotter days during 2020s	Hotter days during 2050s	Hotter days during 2080s
Annual	3	3	6	12
Winter (Jan - Feb)	3	4	12	25
Pre Monsoon (Mar - May)	3	9	19	26
Monsoon (June - Sept)	3	2	6	19
Post Monsoon (Oct - Dec)	3	8	16	25

With the projected warming over Cuttack district, increases in the number of warmer nights (Tmin ≥ 90th percentile) are also expected. The projected annual and seasonal mean changes in number of warmer nights over Cuttack district are provided in Table 2-8. On an annual mean basis, the total count of warmer nights is expected to increase on an average by about 17 days over Cuttack by the end of this century. During pre-monsoon and monsoon seasons, the peak in increase in number of nights with warmer nighttime surface air temperatures is projected at all time-slices. The projected change in number of warmer nights over Cuttack district is likely to be least during post-monsoon season during 2050s and beyond. Maximum number of days with increase in warm nights spatially averaged over Cuttack at all time-slices appears to occur in the months of July – August in a year.

Table 2-8: Projected changes in area averaged increases in number of warm nights over Cuttack district with respect to baseline at different time scales

Time Period	Average number of warm nights (Tmin > 90th percentile)	Average increase in number of warm nights (Tmin > 90th percentile)		
	Warmer nights in Baseline	Warmer nights during 2020s	Warmer nights during 2050s	Warmer nights during 2080s
Annual	3	9	14	17
Winter (Jan - Feb)	3	6	14	25
Pre Monsoon (Mar - May)	3	11	18	26
Monsoon (June - Sept)	3	14	27	27
Post Monsoon (Oct - Dec)	3	5	9	12

The analysis presented in Table 2-7 and Table 2-8 above suggest that both the hotter days and warmer nights in Cuttack district are likely to increase significantly by the end of this century. This would mean that the heat wave conditions should increase in both intensity and frequency during the pre-monsoon season in Cuttack district in the future. With the rise in surface air temperatures, the frequency of heat waves (number of heat waves lasting for 6 consecutive days or longer) is expected to increase as well. Our analysis suggests that about 3 to 5 more severe heat wave spells could be expected to occur by the end of this century. On a shorter time scale, the prevailing atmospheric circulation would modulate the severity of heat wave during pre-monsoon season in a year over the region and could be linked to quasi-periodic ENSO events or otherwise in the Central equatorial Pacific Ocean.

2.7.2 Projected changes in wet and very wet rainfall spells in Cuttack

IPCC findings suggest that the proportion of total rainfall from heavy rainfalls will increase in the 21st century in some seasons (IPCC, 2012). These increases in heavy rainfall could contribute to increases in localized flooding. The future projections suggest that precipitation intensity (e.g., proportionately more precipitation per precipitation event) is projected to increase over most regions, and the increase in precipitation extremes is greater than changes in mean precipitation. Heavy precipitation intensification is now emerging in the observed records across many regions of the world. Changes in extreme precipitation events have been observed in Odisha state as well in the recent past (e.g., years 2001-15 relative to years 1986-2000).

Cuttack normally receives an average annual rainfall of about 144.39 cm. The strength of the southwest monsoon in Cuttack during the season in a year depends on the frequency, the tracks and the strength of synoptic systems such as monsoon lows and depressions. About 75% to 80% of rainfall is received from June to September. Heavy rainfall is experienced by the city in the months of July and August (peak monsoon season). During March - May, the hot-weather pre-monsoon season, thunderstorm activity accounts for some rainfall in Cuttack. During post-monsoon season also, some rains occur due to the remnant NE monsoon and/or cyclonic storms developing in Bay of Bengal and hitting the Indian east coast.

The heavy rains and floods over vast areas of the delta region of Mahanadi river system are common during the monsoon season. In Cuttack (situated on the delta formed by Mahanadi and its subsidiaries), more than 50% of the city is exposed to extreme flood risk basically due to urban flooding, which is due to poor drainage facilities including narrow channel exits, encroachment of flood plain areas, and choking of drains due to dumping of solid waste. Climate change could exacerbate the flood intensity and frequency in this district with more intense rainfall spells. It is also projected that in a warmer atmosphere, cyclones intensify and lead to heavier rainfall episodes. Therefore, occurrence of flash floods during the post monsoon season cannot be ruled out. In order to assess the likely changes in high intensity rainfall in a warmer atmosphere, we have derived the projected changes in seasonal and annual means of area averaged change in wet day rainfall (R_{tot} > 95th percentile) and very wet day rainfall (R_{tot} > 99th percentile) over Cuttack city with respect to baseline at different time scales. These are presented in Table 2-9 and Table 2-10 below.

Table 2-9: Projected changes in area averaged change in wet day rainfall over Cuttack district with respect to baseline at different time scales

Time Period	Wet day rainfall (mm/month) for Baseline period (1961-90)	Change in rainfall (mm/month)		
		ΔP, 2020s	ΔP, 2050s	ΔP, 2080s
Annual	41	3	8	26
Winter (Jan - Feb)	6	0	4	0
Pre Monsoon (Mar - May)	17	0	0	1
Monsoon (June - Sept)	54	7	16	60
Post Monsoon (Oct - Dec)	35	-5	-4	-13

Table 2-10: Projected changes in area averaged change in very wet day rainfall over Cuttack district with respect to baseline at different time scales

Time Period	Very wet day rainfall (mm/month) for Baseline period (1961-90)	Change in rainfall (mm/month)		
		ΔP, 2020s	ΔP, 2050s	ΔP, 2080s
Annual	13	1	5	14
Winter (Jan - Feb)	3	0	3	1
Pre Monsoon (Mar - May)	7	2	0	1
Monsoon (June - Sept)	15	4	9	27
Post Monsoon (Oct - Dec)	12	-2	0	-5

The findings presented in Table 2-9 suggest that on an annual mean basis, as much as 26 mm per month of rainfall could be added to the present-day monthly mean due to wet days with total rainfall being in excess of the 95th percentile. Further, the contribution of rainfall on days with very wet day rainfall (R_{tot} > 99th percentile) would be 14 mm in a month (Table 2-10). The wet day rainfall exceeding 95th percentile during the monsoon season would add to about 60 mm of monthly total rainfall by the end of the 21st century. Similarly, very wet day rainfall exceeding the 99th percentile during monsoon season would add to about 27 mm of monthly total rainfall by the end of the 21st century. This clearly suggests that both heavy and very heavy rainfall episodes are likely to occur in Cuttack more often than now by the end of 21st century. This could have serious implications for more frequent and severe floods in Cuttack in future.

3 Component 2: Development of Exposure Database

Exposure data pertains to all assets and life that can be potentially exposed to any hazard. It is critical to understand the location, type, quantity, and strength of the elements to withstand the hazards they might be exposed. A well-designed GIS exposure database is indispensable for carrying out multi-variant spatial analysis for hazard risk assessment across the city. Such a database will also help facilitate mainstreaming DRR activities into for risk resilient city development and to improve preparedness, response, and relief activities.

3.1 Analysis of Exposure Elements

There are 59 wards in Cuttack municipality (Figure 3-1). Detailed analysis of each exposure element is presented in the following subsections. The data sources for developing the exposure database and their details are provided in Table 8-3 in the annexure 8.2.

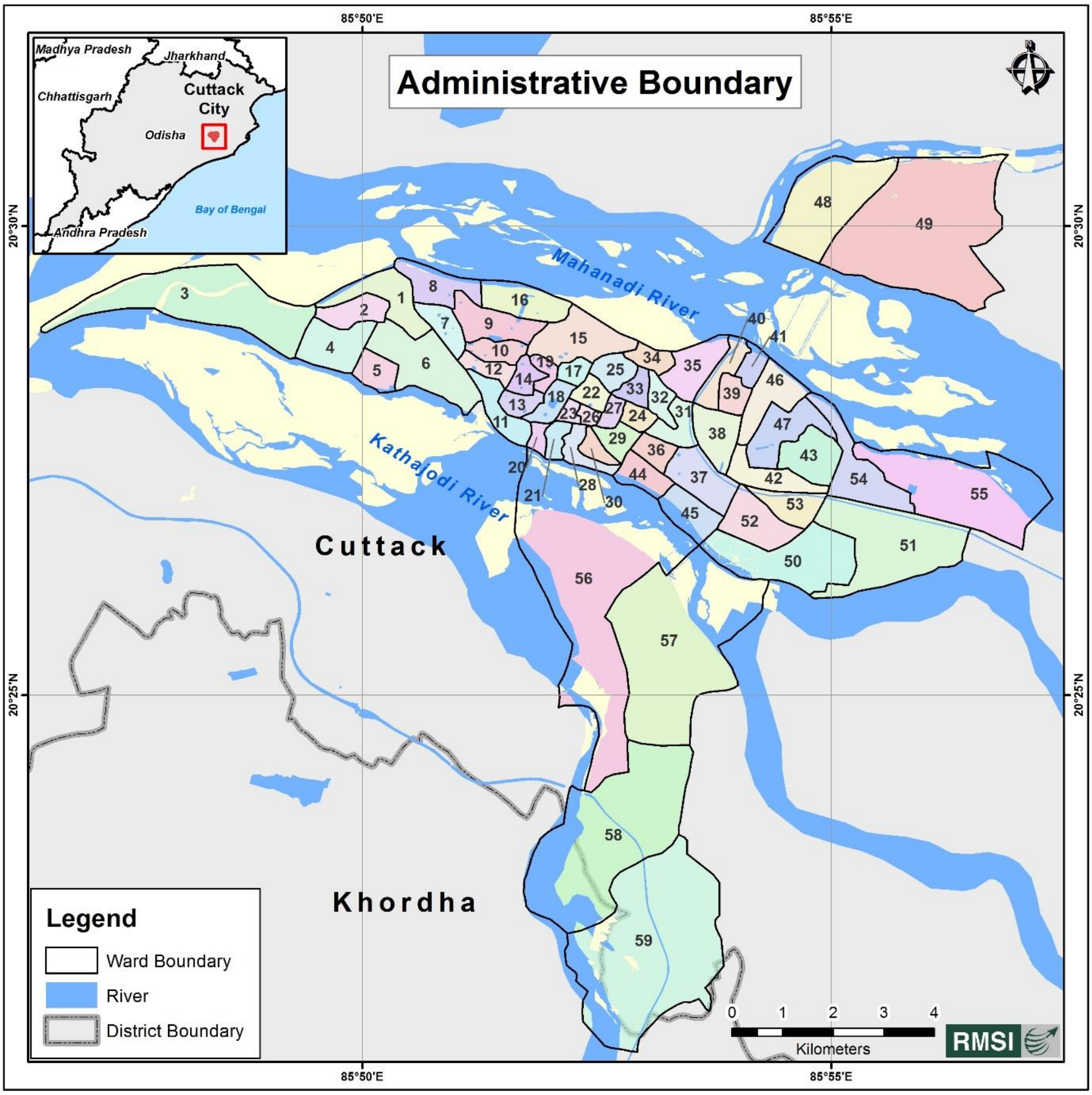


Figure 3-1: Cuttack city administrative boundary

3.1.1 DEMOGRAPHY

As per Census 2011, the total population of Cuttack city is about 6.10 lakhs, which is approximately 23% of the district population. Applying the annual growth, 2017 population figures were estimated which is to the tune of 6.59 lakhs.

3.1.2 HOUSING

About 1.94 lakh houses have been estimated for 2017, out of which about 92% are occupied and the remaining 8% are vacant (Figure 3-2, left). The occupancy based distribution of housing shows that about 74% of the houses are used for residential purposes, whereas, about 23% are used for commercial or residential-cum-commercial use. The remaining (about 3%) houses are used for other purposes that include industrial activities, social and public uses, viz., schools, colleges, hospitals, dispensaries, religious places etc. Figure 3-2, (right) provides the distribution of houses based on their occupancy.

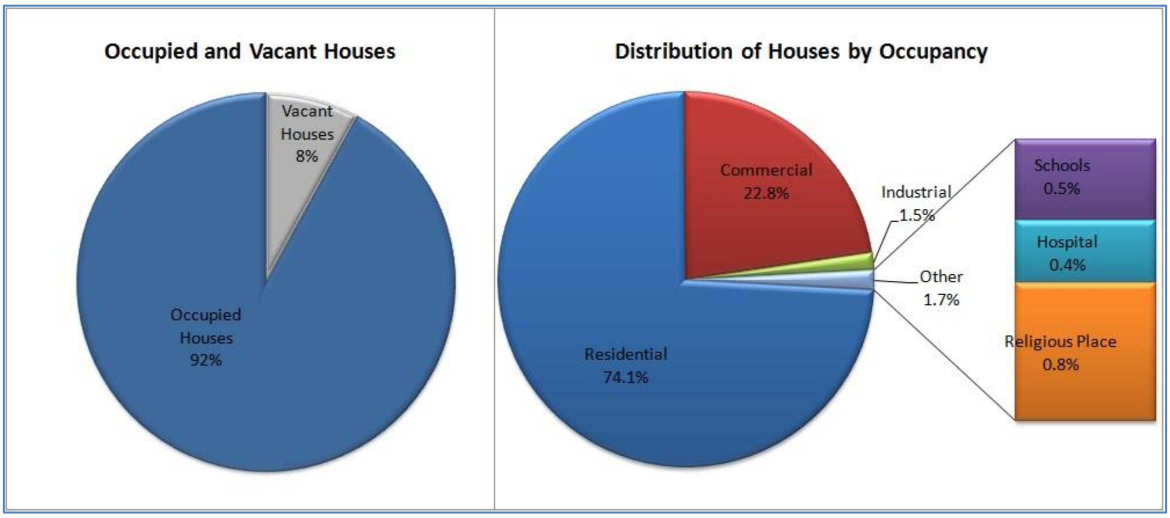


Figure 3-2: Percentage of occupied and vacant houses (left), and percentage of Census houses based by occupancy (right)

As Census data on occupancy type do not have spatial information and statistical techniques were used to distribute occupancy type on built up at ward.

3.1.3 BUILDING STRUCTURE CLASSES FOR VARIOUS OCCUPANCIES

3.1.3.1 Residential

The general residential houses in Cuttack municipality are classified into independent houses, apartments, villas, and huts. Sample photographs of each category are provided in Figure 3-3.

Figure 3-3: Different types of residential houses

Out of the total estimated 1.94 lakh houses, about 1.33 lakhs are residential houses distributed across 59 wards.

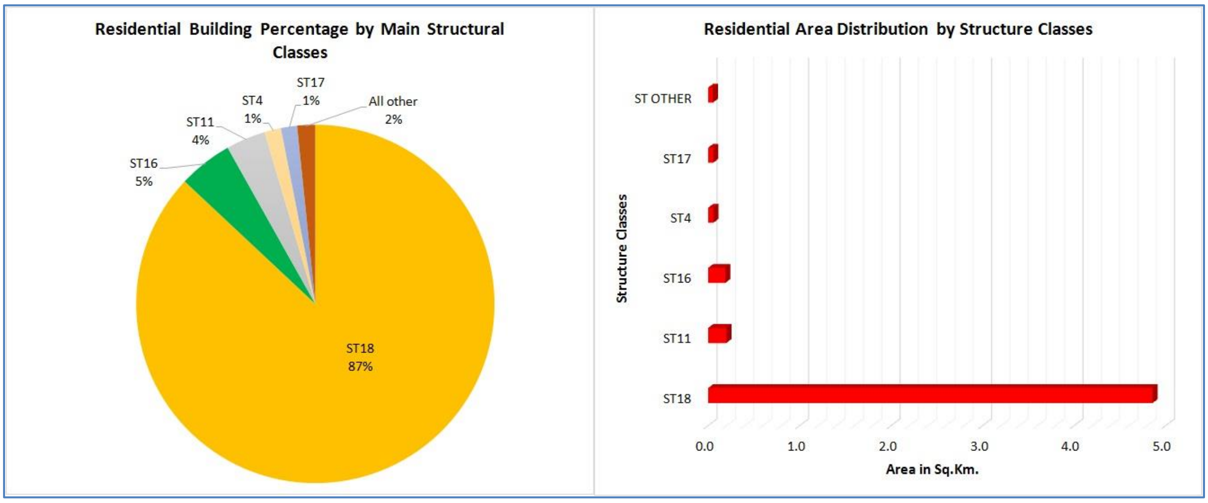


Figure 3-4: Percentage of residential buildings by structure types (left) and their respective areas (right)

Independent houses contribute a substantial share to residential buildings in the municipality. The structural types delineated based on Census 2011 wall and roof combination has been detailed in the Table 8-9*.* Structural types ST18 and ST11 comprise about 115 thousand and 6 thousand buildings (about 87% and 5% of the total residential buildings), respectively. ST16 is the next dominant class that consists of about 4 thousand of the total residential buildings (4%). When we consider the built-up areas under different structural classes, residential buildings collectively cover about 5.41 sq km built-up area in the city (Table 3-1). ST18 and ST11 are the top two classes that collectively account for 93% of the total residential built-up area, where as ST16, and ST4 are the next major classes, which collectively cover 5% of the total residential area. The total exposure value of residential buildings is estimated at around INR 7,205 crores. Count of residential buildings and their built-up areas based on the major structural types is presented in Table 3-1.

Table 3-1: Residential building counts and built-up area by structural types

Structure type	ST18	ST11	ST16	ST4	ST17	All other	Grand Total
Count of Houses	115,675	6,488	4,745	1,976	1,938	2,168	132,990
Area in sq km	4.86	0.20	0.19	0.06	0.06	0.05	5

3.1.3.2 Commercial

The Census provides number of shops and offices, hotels, lodges, guesthouses, residence-cum other uses, and other non-residential houses at municipal level. All these categories of data were combined together to get the total number of commercial houses in the city . It was further distributed over the wards, based on the household number available at each ward level in the demographic data. Sample photographs of some of the commercial buildings are provided in Figure 3-5.

Note: commercial buildings do not include schools and colleges, hospitals and dispensaries, places of worship, and industries.

Figure 3-5: Different types of commercial buildings/centers

A total of 40.9 thousand commercial buildings are estimated, which cover a total built-up area of about 1.67 sq. km. Ward number 56 has the highest percentage of commercial built-up area (about 9% of total commercial built-up area), followed by ward 57 and ward 49 (about 8% and 6% respectively). The total exposure value of commercial buildings is estimated at around INR 2,285 crores. Figure 3-6 below presents the distribution of main structural classes for commercial buildings. ST18 and ST16 are the dominant structural types for commercial buildings (88% and 6% of total commercial buildings, respectively) in the city.

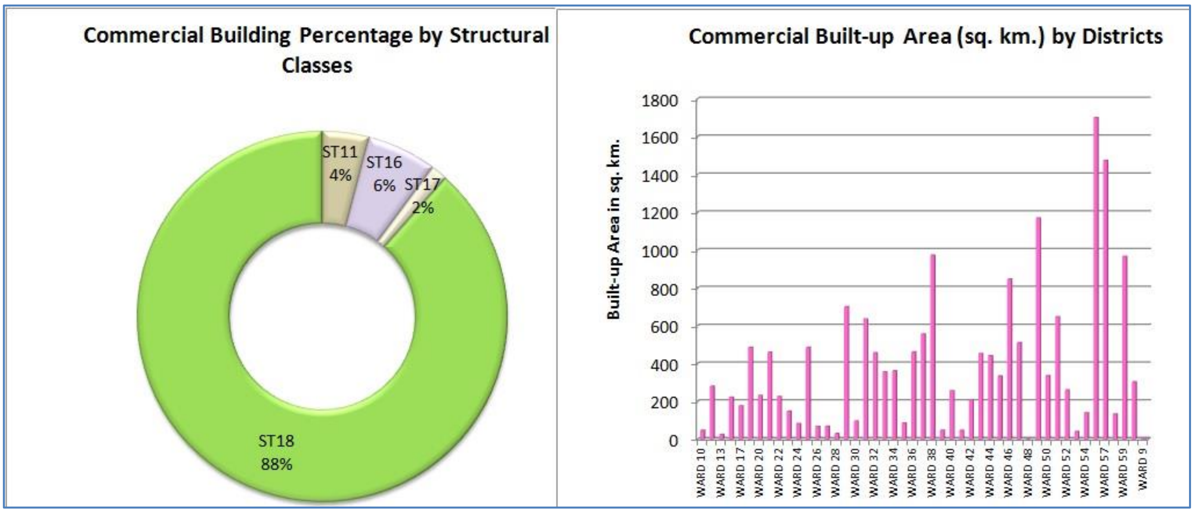


Figure 3-6: Percentage distribution of commercial buildings by structural types (left) and built-up area by wards (right)

3.1.3.3 Industrial

Census 2011 provides number of industries at city level. Using building agglomeration data of industries, city level number of industries was distributed over the wards.

Out of 2,621 industries in the city, majority of industries are located in ward number 49 (77% of total industries), ward number 50 (14%), ward number 42 (3%), and ward number 59 (3%). Total industrial built-up area in the city is estimated at about 0.89 sq. km (Figure 3-7). The total exposure value of industrial building is estimated at around INR 1,543 crores.

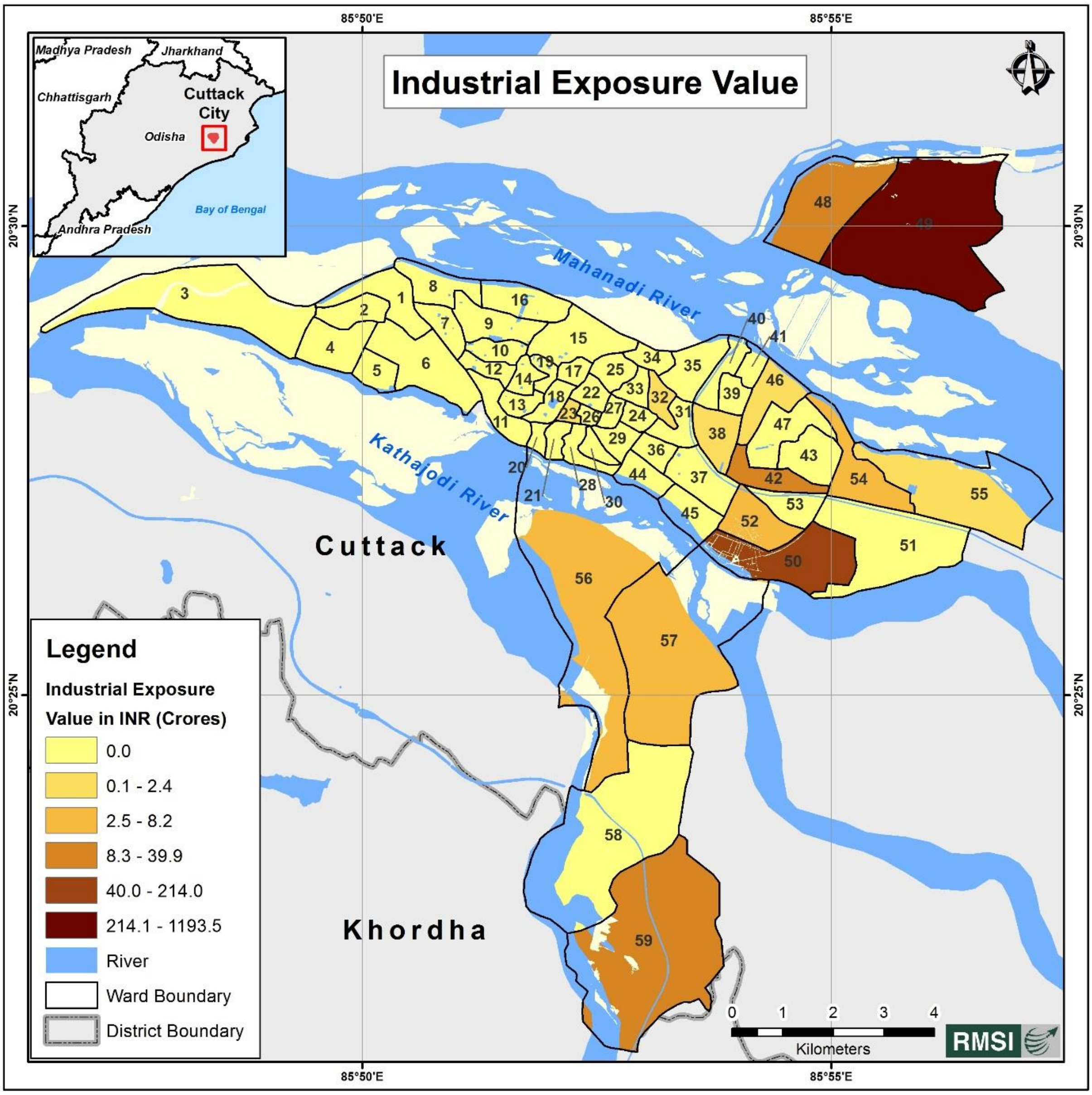


Figure 3-7: Distribution of industries by ward

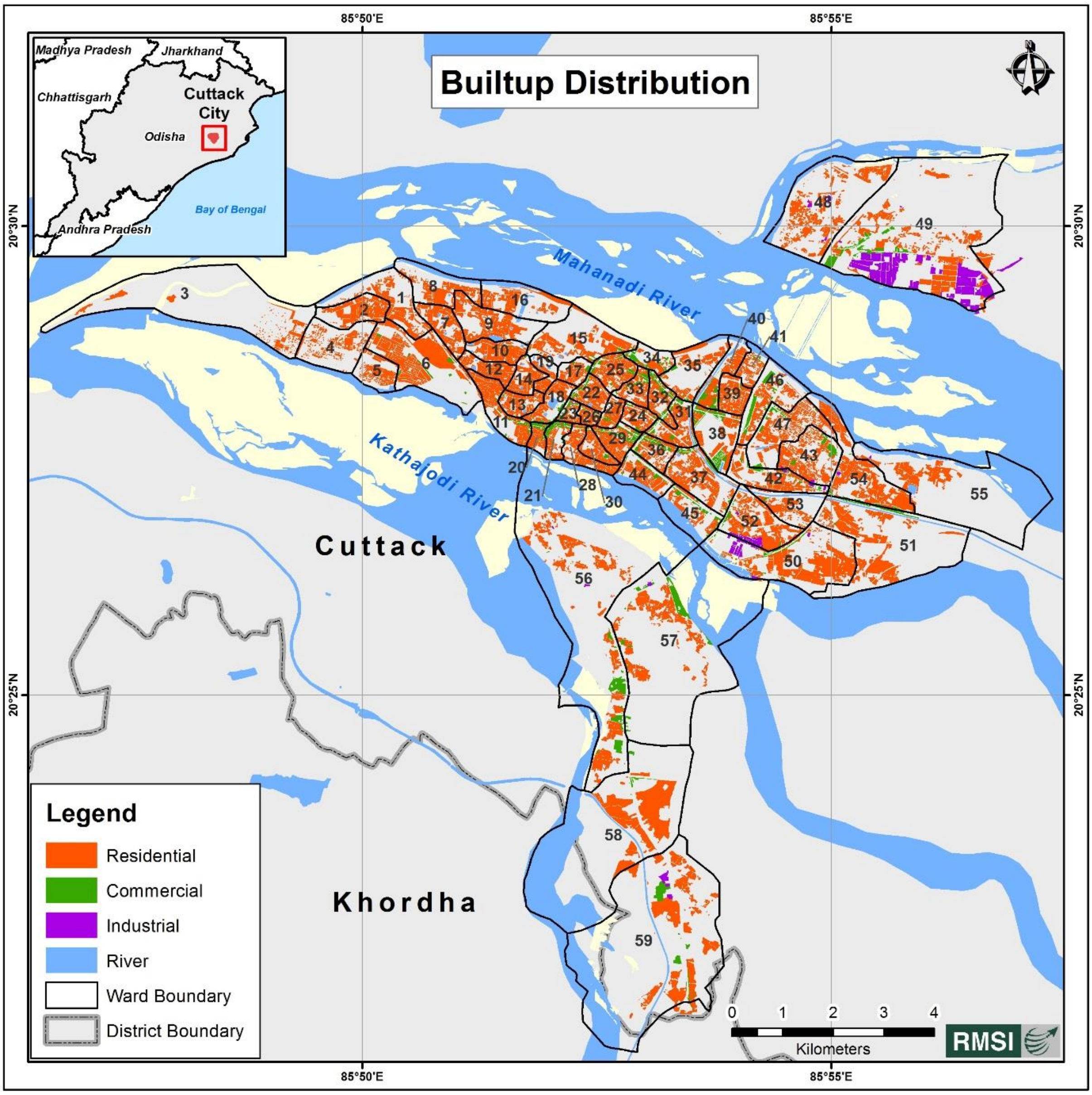


Figure 3-8: Distribution of built up area based on occupancy

3.1.4 OTHERS

3.1.4.1 Religious Places

The sources of religious building data are Census of India (2011), SOI, and Cuttack Disaster Management Authority (Figure 3-9). However, the data received from IIT Kharagpur is being used as site-specific data for further updates and modifications.

For 2017, the estimated number of religious places in the city is 1,480, which cover about 0.06 sq. km of built-up area. The total exposure value of religious buildings is estimated at around INR 56.9 crores. As per available data, Ward No-01 has the maximum number of religious places (50) followed by Ward No-47 (40).

3.1.4.2 Cultural Heritage Sites

Cultural heritage comprises of the sources and evidence of human history and culture regardless of origin, development, and level of preservation, and the cultural assets associated with this. Because of their cultural and historic value, cultural heritage sites need to be protected and preserved.

Cultural heritage conservation helps a community not only protect economically valuable physical assets, but also preserves its practices, history, and environment, and a sense of continuity and identity. These are invaluable, so the losses cannot be calculated in monetary terms. However, the impact of hazards on these assets is being considered in risk assessment. The sources of cultural heritage sites are the Department of Tourism and the Archaeological Survey of India (ASI). There is only one cultural heritage site located in the city.

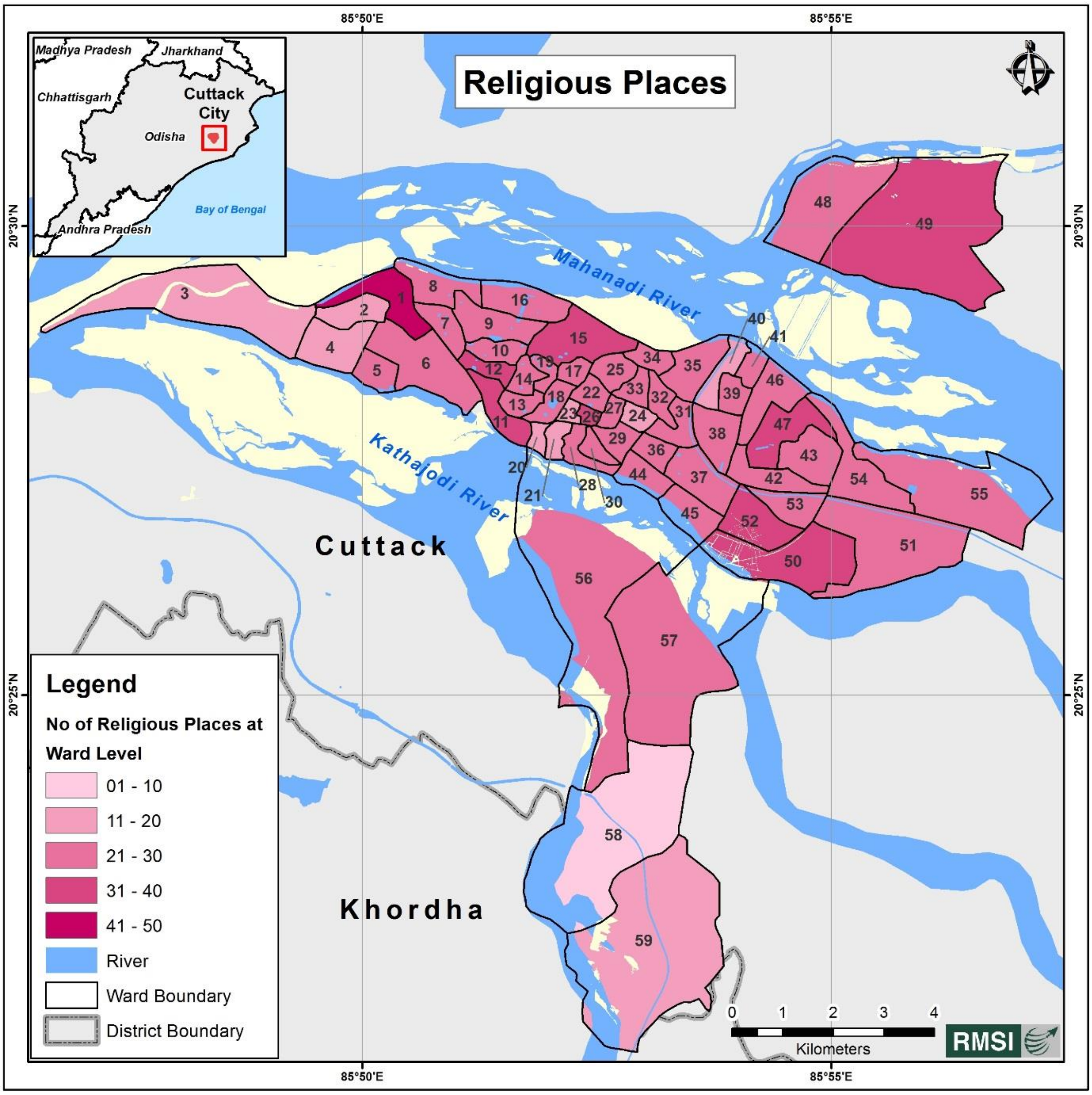


Figure 3-9: Distribution of religious places

3.2 Infrastructure Data

3.2.1 ESSENTIAL FACILITIES

Educational facilities and health-facilities have been included under essential facilities. These play a critical role in mitigation, response, and recovery operations. The following sections discuss the quantification of exposure values for these facilities.

3.2.1.1 Educational Facilities

Educational institutions play a critical role in mitigation (awareness development) and response (as shelters) planning. Data from Census 2011 at municipal level has been further projected to 2017 based on population growth and used for the analysis. This projected data has been distributed over the wards based on household count.

There are 870 educational institutions located in the city that comprise of schools, colleges, universities, and other educational institutes. Together, they cover about 0.57 sq. km of built-up area. The highest number of educational institutions are located in Ward No-01 (29 institutions) followed by Ward No-47 and Ward No-26 (23 and 22 respectively). Figure 3-10 (left) shows percentage distribution of number of educational institutions by their types and Figure 3-10 (right) shows distribution of number of educational institutions by wards.

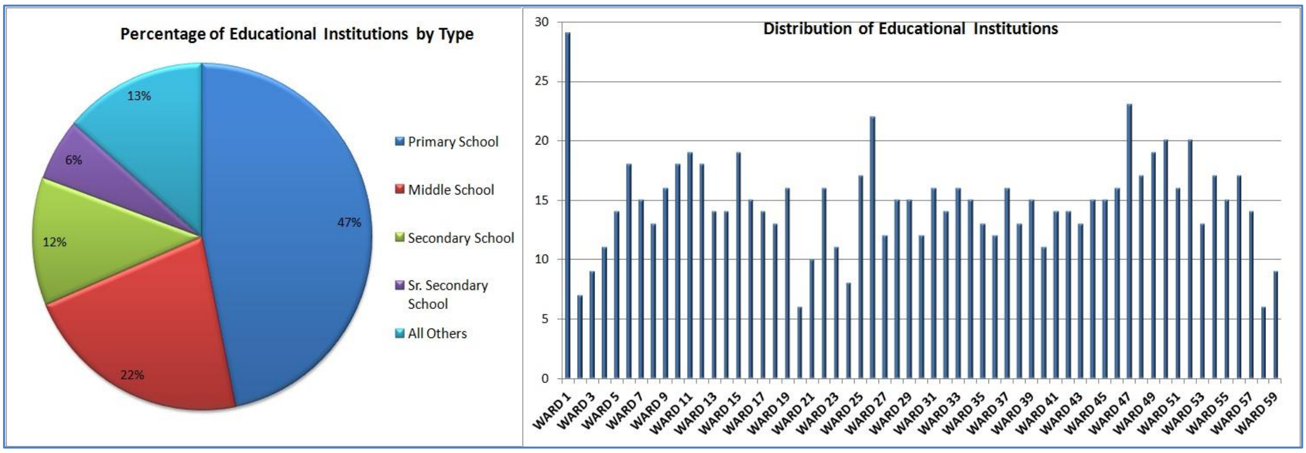


Figure 3-10: Percentage of educational institutes by type (left) and distribution of educational institutes by wards (right)

The ward wise estimated areas of different structure-types were multiplied with the per unit replacement costs of respective structure types. Based on this, the total estimated exposure value for educational institutions is around INR 792 crores. The distribution of educational institutions is presented in Figure 3-11 at the end of this sub-section.

3.2.1.2 Health Facilities

Health facilities play a critical role in mitigation, response and recovery operations. Similar to educational facilities, for health facility data we used to same statistical method to get the 2017 projected figures at ward level as ward level latest figures are not available.

There are 672 health facility centers located in the city. The ward-level estimated built-up area of health facilities were multiplied with the per unit replacement costs. for the exposure value of health facilities is estimated at INR 344 crores. The distribution of health facilities is presented in Figure 3-12 at the end of this sub-section.

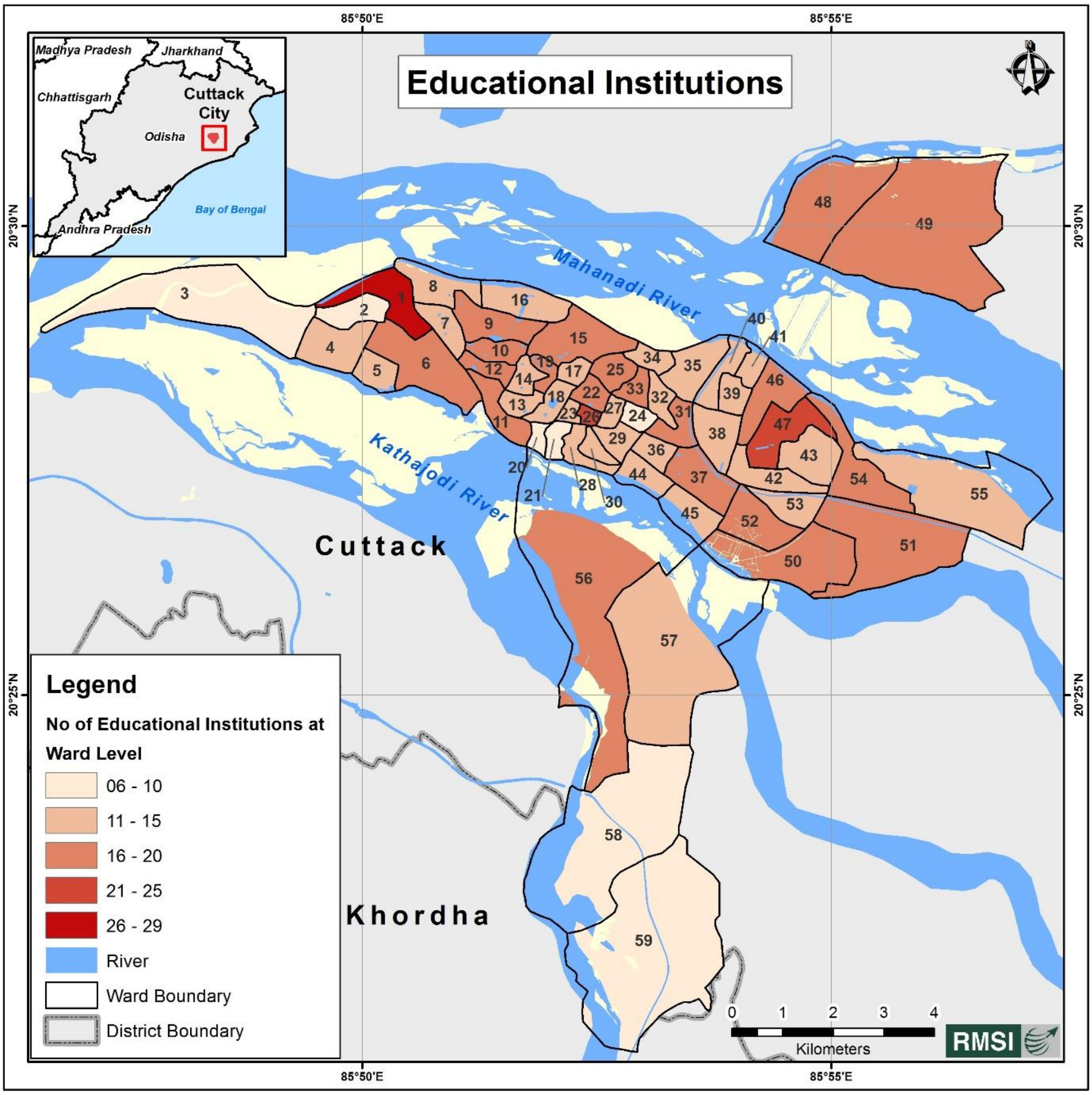


Figure 3-11: Distribution of educational institutions

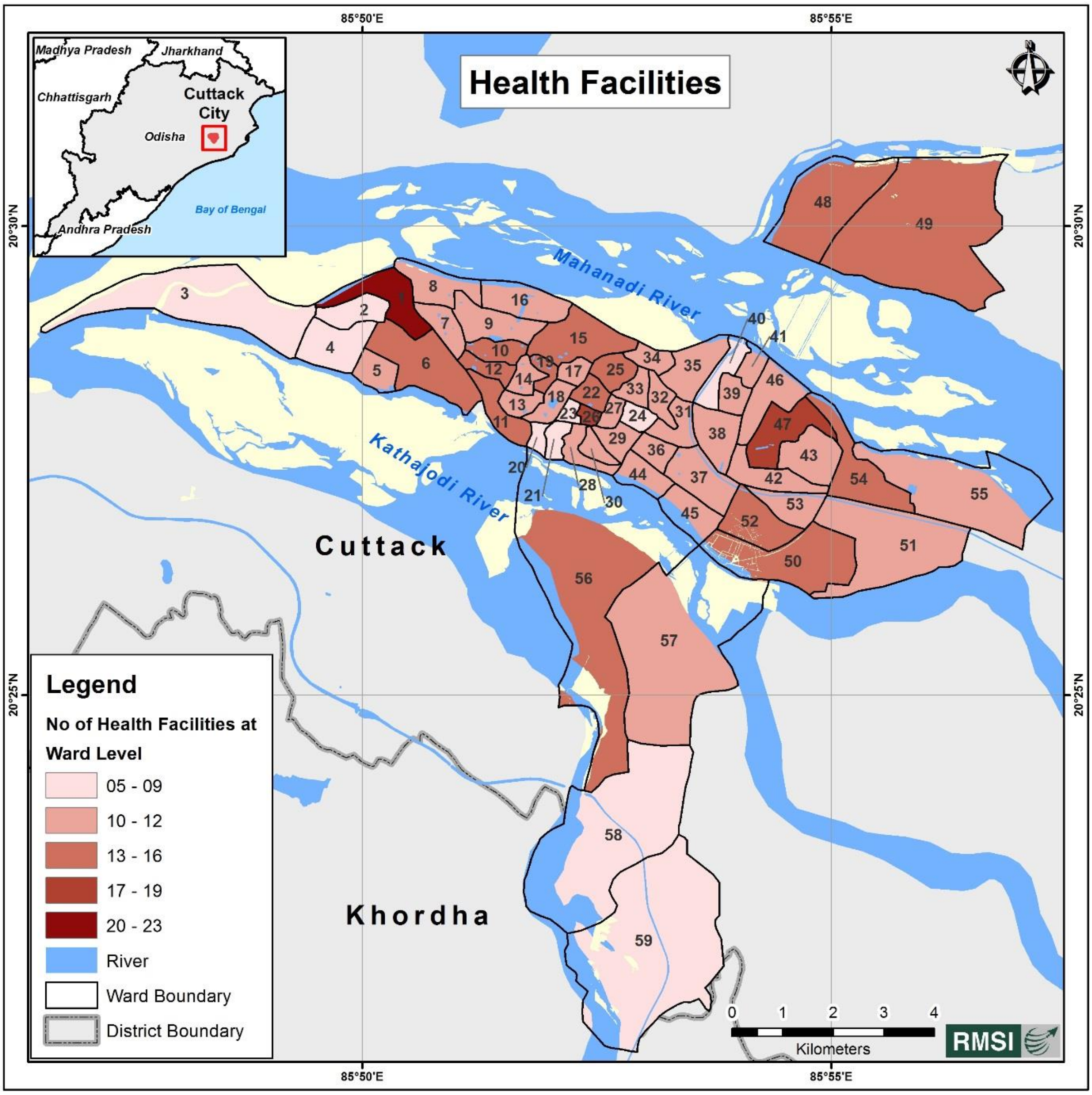


Figure 3-12: Distribution of health facilities

3.2.2 GOVERNMENT/ PUBLIC BUILDINGS

The following sections discuss the important government/ public buildings that include fire stations, police stations, and administrative headquarters.

3.2.2.1 Fire Stations

Fire services are the first responders to any kind of emergency and play a critical role in risk mitigation. The source of data for fire stations is the State Fire Service Department. There are 3 fire stations in the city.

In terms of availability of vehicles in fire stations, Cuttack Fire Station has 9 fire vehicles (70% of total number in the city), and Abhinaba Bidanasi Fire Station and Chauliaganja Fire Station have 2 each (Figure 3-13). Further, in terms of bay systems (garages for fire fighting vehicles) in fire stations, Cuttack has 6 bays and other two fire stations have 2 bays each.

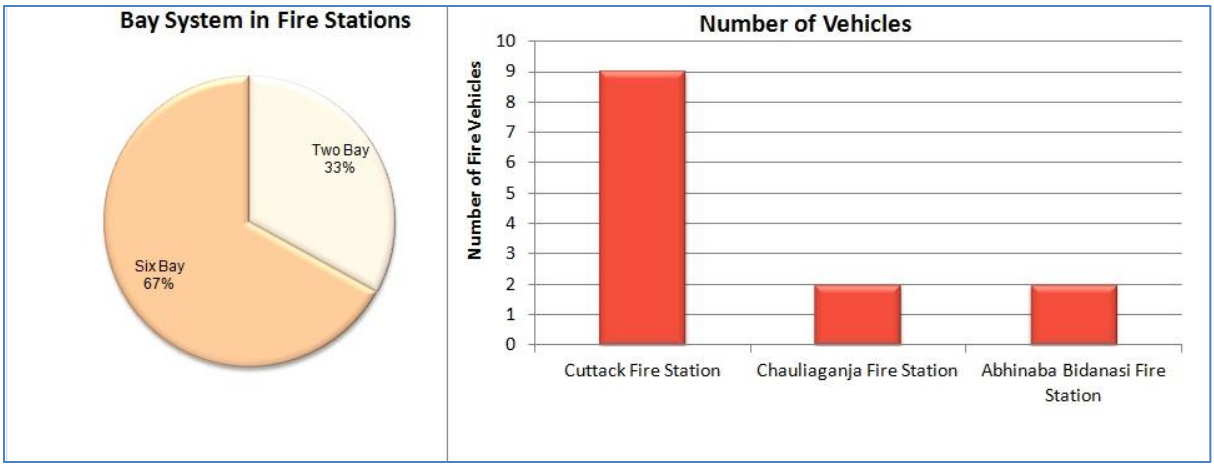


Figure 3-13: Percentage of fire stations by number of bay systems (left) and percentage of fire vehicles by Fire station (right)

The locations of fire stations in the city are presented in Figure 3-14. The total exposure value is estimated at around INR 1.19 crores.

3.2.2.2 Administrative Headquarters

All the important government offices of the city are located in the administrative headquarters. There is a district headquarter in the city and the estimated exposure value is 1.58 crores.

3.2.2.3 Police Stations

Data source for police stations of the city was collected from the Police Commissionerate of Bhubaneswar-Cuttack. There are 17 police stations/police check posts distributed across the city. Considering the built up and structure types of the police station buildings the exposure value for police stations is estimated to be INR 16.32 crores (Figure 3-14).

Figure 3-14: Distribution of fire and police stations

3.2.3 TRANSPORTATION

During disasters, transportation systems play an important role in rescue and recovery operations. Roads, bridges, and railways are considered for exposure analysis in the sections presented below.

3.2.3.1 Roads

Road data provides information regarding the various types of roads as well as their respective lengths. The available data classifies roads into four categories, namely, state highways, major roads, and minor and link roads. Ward level total lengths of various categories of roads were calculated to compute the exposure value. In order to estimate the replacement cost of roads, unit costs of various road types were considered.

The city has a total road network length of about 716 km. The road network comprises of about 41 km of national highway, 4 km state highway, 80 km of major roads, 3 km minor roads, and remaining 587 km of link roads (Figure 3-15).

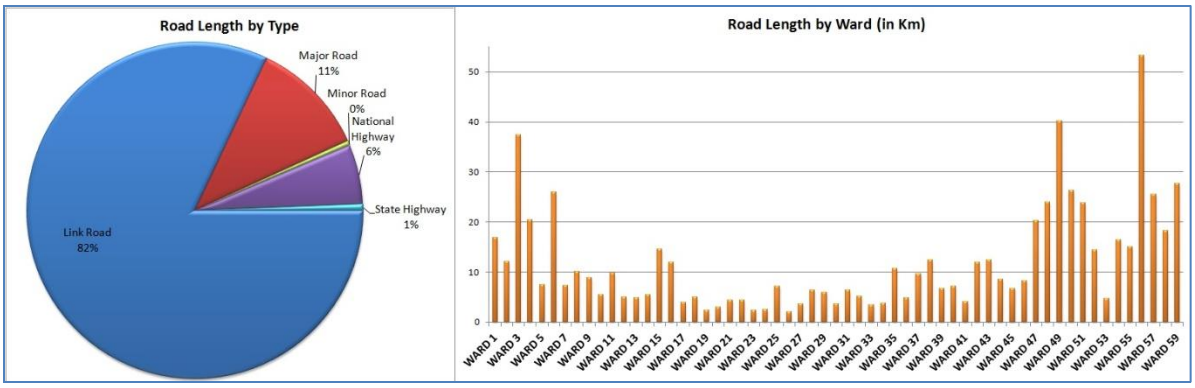


Figure 3-15: Percentage of road length for Cuttack by road type (left) and ward-level total road lengths (right)

The total estimated exposure value for the road network is estimated at INR 2,268 crores. Figure 3-16 presents the road network of Cuttack.

3.2.3.2 Railways

In order to estimate the replacement cost of the railway network, unit cost of the railway network was determined by taking inputs from International Railway Equipment Exhibition[1] (IREE), and Indian railways[2] websites.

The total length of the rail network in the city is about 41.98 km. The length of the railway network was multiplied with per unit replacement costs of the railway network. Based on this the total estimated exposure value for the railway network is estimated at INR 265 crores. Figure 3-16 shows the railway network in the city of Cuttack.

3.2.3.3 Bridges

As part of bridge database, total numbers and lengths of bridges at ward level were calculated to compute the exposure value. The total estimated exposure value for bridges was estimated at INR 1,301 crores, out of which railway bridges contribute INR 401 crores. Figure 3-16 shows bridges, which come under the city.

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[1] http://www.ireeindia.org/RE%20Booklet.pdf

[2] http://www.nr.indianrailways.gov.in/view_detail.jsp?lang=0&dcd=3265&id=0,4,268

Figure 3-16: Infrastructure map of Cuttack city

3.2.4 UTILITIES

Utilities considered include electric power, waste water systems, communication systems, oil and gas, and systems that supply potable water. Any disruption in these services due to physical damage not only causes direct economic losses, but it also has indirect impacts in terms of disrupting livelihoods as well as slowing or disrupting post-disaster relief work.

3.2.4.1 Waste Water

The spatial data for wastewater network is not available from city or the line department. Census (2011) provides town wise percentage of open and closed drainage systems. Using this percentage, approximate length of waste water network has been estimated with the aid of the road network data, assuming that drainage network is distributed along the road network. The estimated total drainage network length is about 445 km. Multiplying the unit cost with length provides the total estimated exposure value of about INR 222 crores.

3.2.4.2 Potable water

The spatial data for potable water network is not available from any of the sources. Therefore, we used similar approach of estimating the waste water network using Census data and estimated the exposure value applying unit cost. This is estimated to the tune of INR 191 crores.

3.2.4.3 Electric Power Network

Similarly, for assessing the exposure value of electric power network percentage coverage is used along with road network to assess the estimated length of electric power network. In addition, numbers of substations, transmission towers, transformers, and electric poles at ward level have been estimated based on the information collected from literature surveys and previous studies.

The replacement cost of the electric power network has been determined by taking unit cost of the electricity line from the Western Electricity Coordination Council. The replacement costs for the remaining components of electric power network have been estimated using open sources.

The total estimated exposure value for the electric power network has been estimated at INR 394 crores.

3.2.4.4 Communication lines

The estimation of communication systems requires detailed information on the number of communication towers, the length of optical fiber cables, the number of communication stations, and the unit cost of each of them. However, except for ward level census 2011 data on the number of mobile and landline connections, no other information is available on communication systems. In addition, number of telecommunication towers at ward level has been estimated based on information collected through previous studies (Figure 3-17).

In order to estimate the total exposure value of the communication infrastructure, the cost per subscriber for mobile and landline connections in India has been utilized (Figure 3-18). As per data collected from the Telecom Regulatory Authority of India (TRAI) and Bharat Sanchar Nigam Limited (BSNL), the values of infrastructure per subscriber for mobile and landline connections are INR 730 and 4,960 respectively. The total estimated exposure value of the communication system is INR 93 crores.

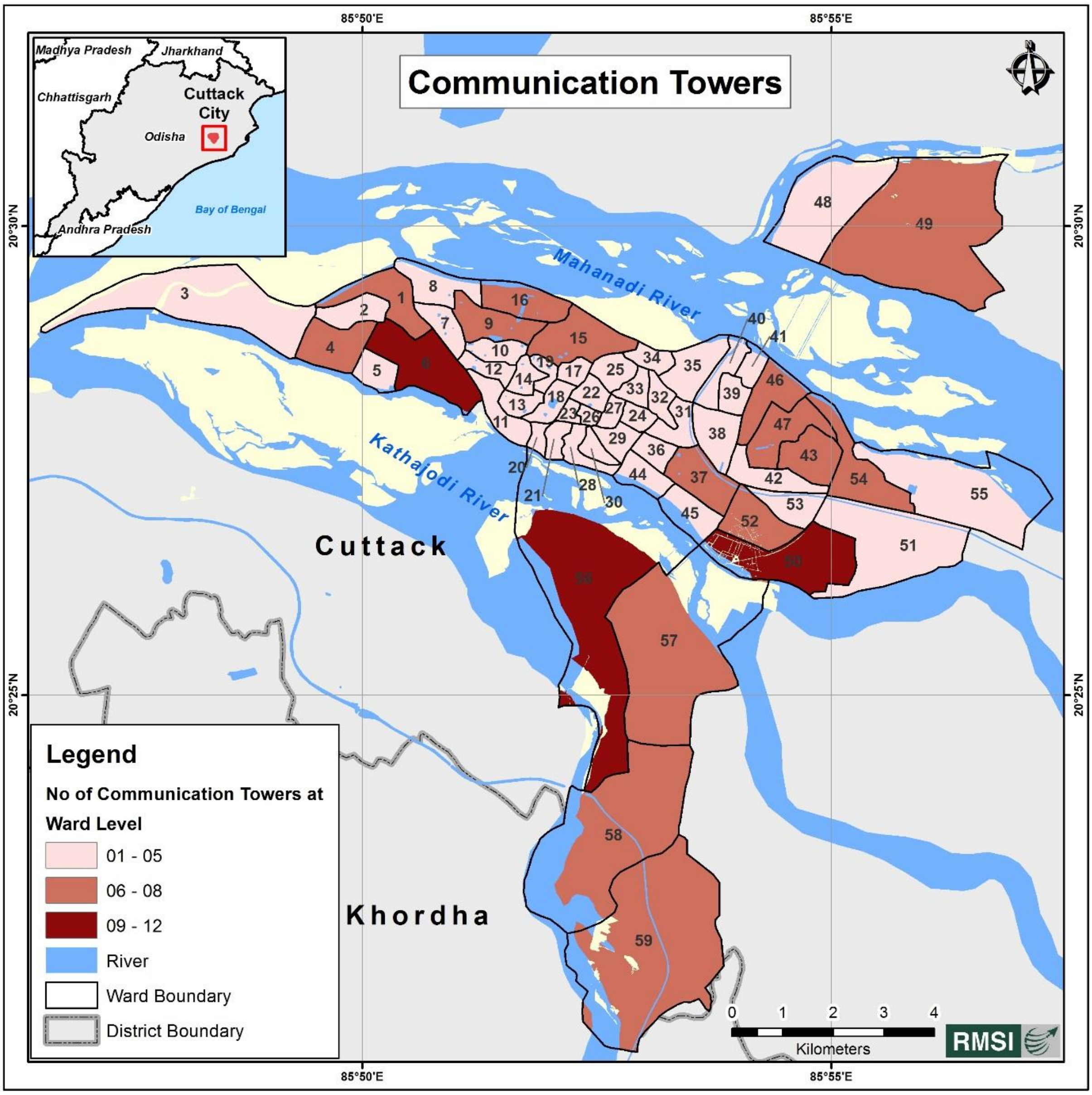

Figure 3-17: Distribution of communication towers

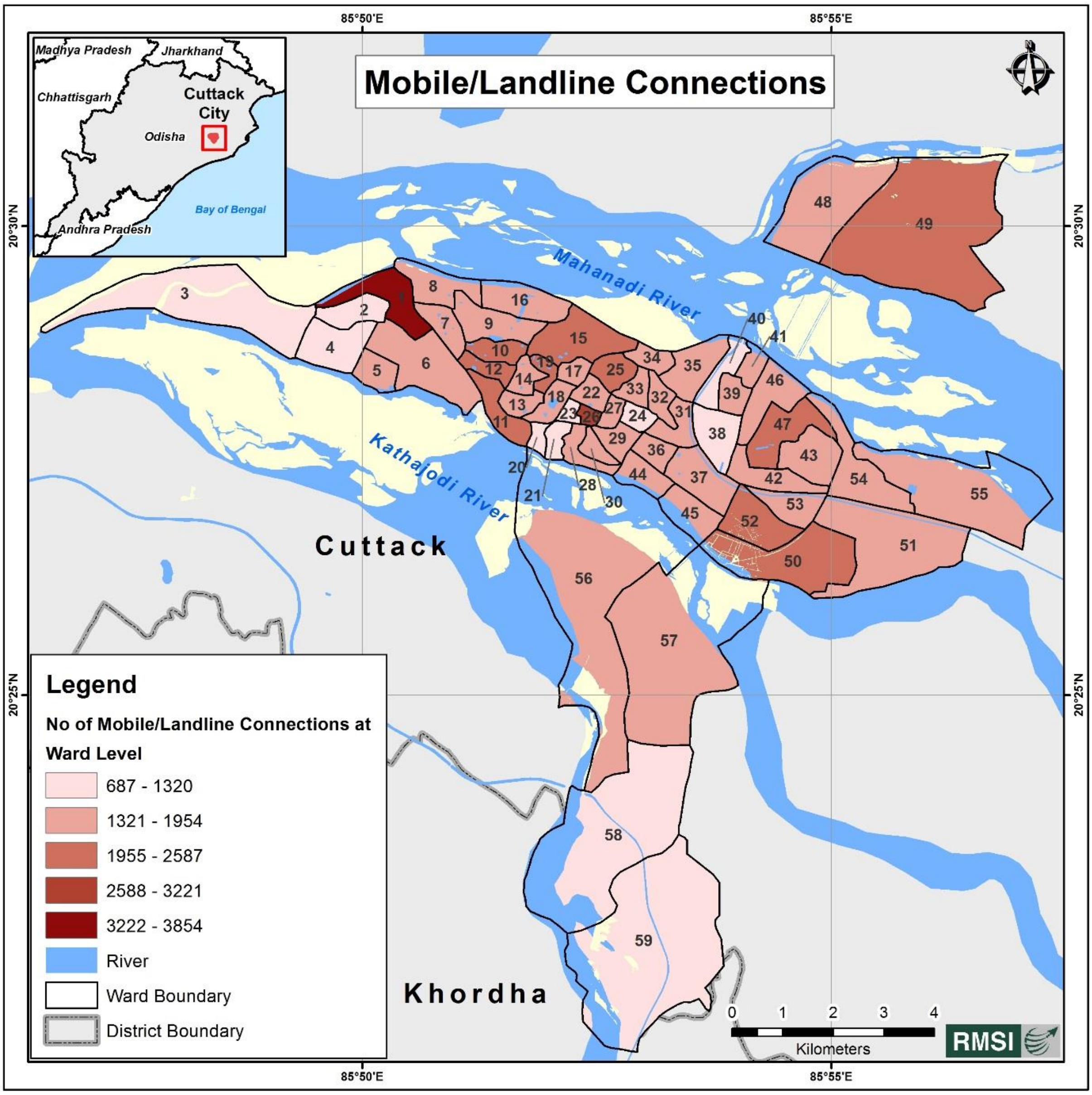

Figure 3-18: Distribution of mobile/landline connections

3.3 Others

3.3.1 EMBANKMENTS

Data for embankments has been received from SOI. This data provides spatial distribution and elevation of embankments is collected based on field observations. Distribution of embankments in Cuttack has been shown in Figure 3-19.

Figure 3-19: Embankment Locations

3.4 Exposure Summary Results

The total exposure values have been estimated for each type of exposure element. This estimation has been carried out by multiplying the unit replacement cost with corresponding asset length/area to get the total replacement cost for each exposure type. Table 3-2 provides details of estimated values for aggregated and site-specific exposures in the city.

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

S. No.	Exposure Layer	Total Replacement Cost (INR Crores)	Percentage to total exposure value
1	Residential	7,204.6	42
2	Commercial	2,284.7	13
3	Industrial	1,542.5	9
4	Educational institutions	791.7	5
5	Health facilities	344.4	2
6	Religious places	56.9	0
7	Police stations	16.3	0
8	Fire stations	1.2	0
9	Administrative headquarters	1.6	0
10	Bridges	899.9	5
11	Railway bridges	400.7	2
12	Railway lines	264.5	2
13	Roads	2,267.9	13
14	Potable water network	191.3	1
15	Waste water network	222.3	1
16	Communication system	93.4	1
17	Electric power network	394.2	2
	Grand Total	16,978	100

3.4.1 Housing, Public Buildings and Essential Facilities

Figure 3-20 below presents the total exposure values for housing, public buildings, and essential facilities in INR. The total estimated value of different buildings present in the city is more than INR 12,245 crores, out of which residential buildings account for about 59% of the total value, commercial buildings for about 19%, industrial buildings for about 13%, and educational institutes for about 6%.

Figure 3-20, Figure 3-21 and Figure 3-22 provide the total exposure values for all building occupancy classes, transportation assets, and utility assets, respectively. The distribution of residential, commercial, and industrial exposures at ward level has been presented in Figure 3-23, Figure 3-24 and Figure 3-25, respectively.

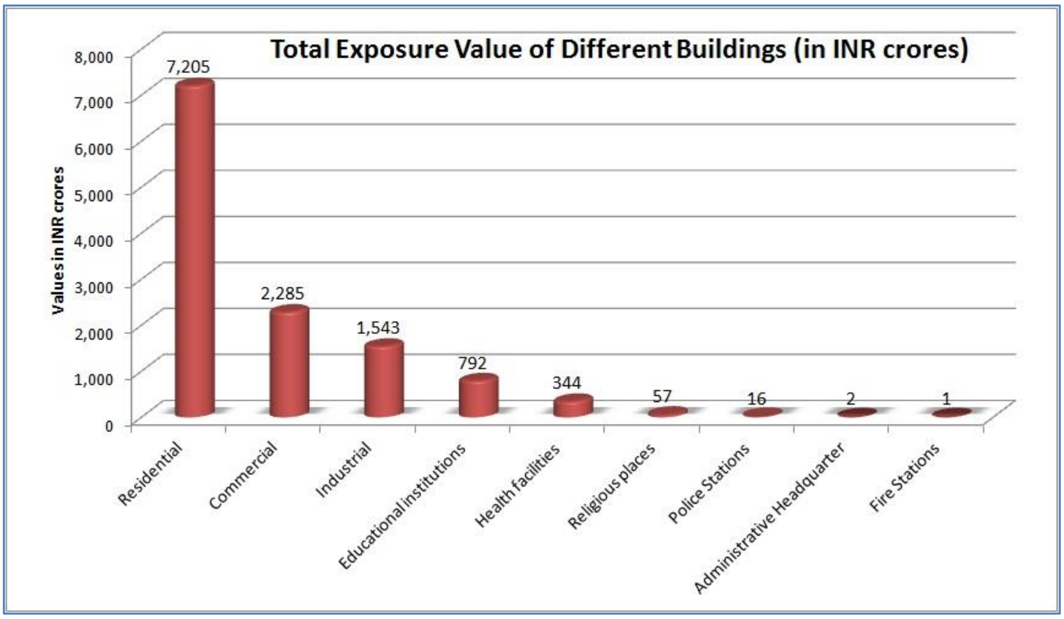

Figure 3-20: Total exposure value of buildings based on uses

3.4.2 TRANSPORTATION

Figure 3-21 below presents the total exposure value for different transport assets in INR. The total estimated value of exposure in all transport categories present in the city is more than INR 3,834 crores. Out of this, road exposure value accounts for about 59% of the total value, bridges for about 34%, railway line for about 7%.

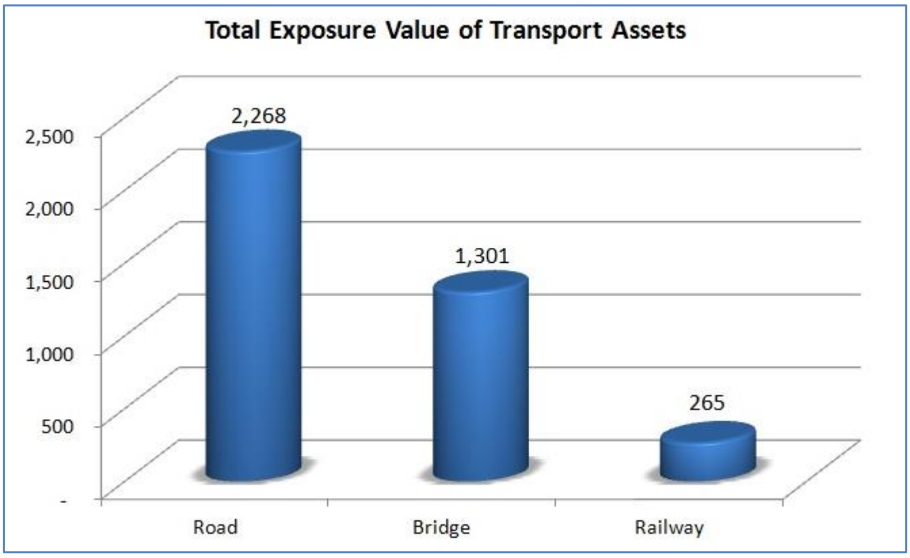

Figure 3-21: Total exposure value of transport assets

3.4.3 UTILITIES

The total estimated value of exposure for all utility categories present in the city is more than INR 901 crores (Figure 3-22). Out of this, electricity power network exposure value accounts for about 44% of the total value, waste water network for about 25%, portable water network for about 21%, and communication for about 10%.

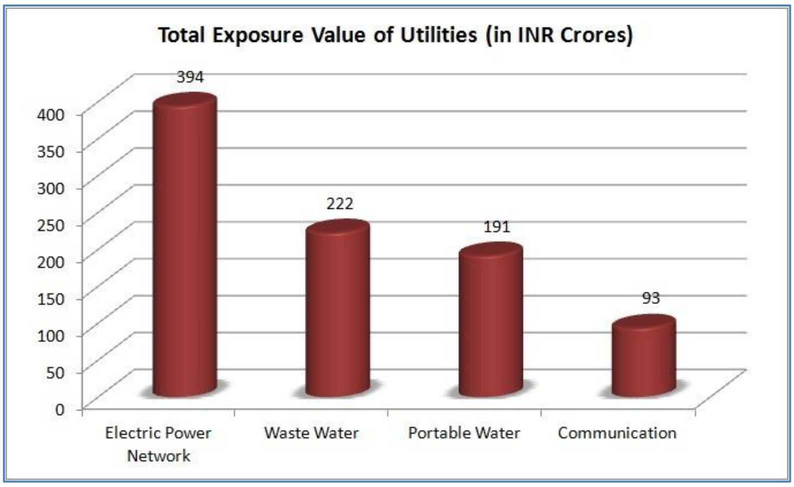

Figure 3-22: Total exposure value of utilities

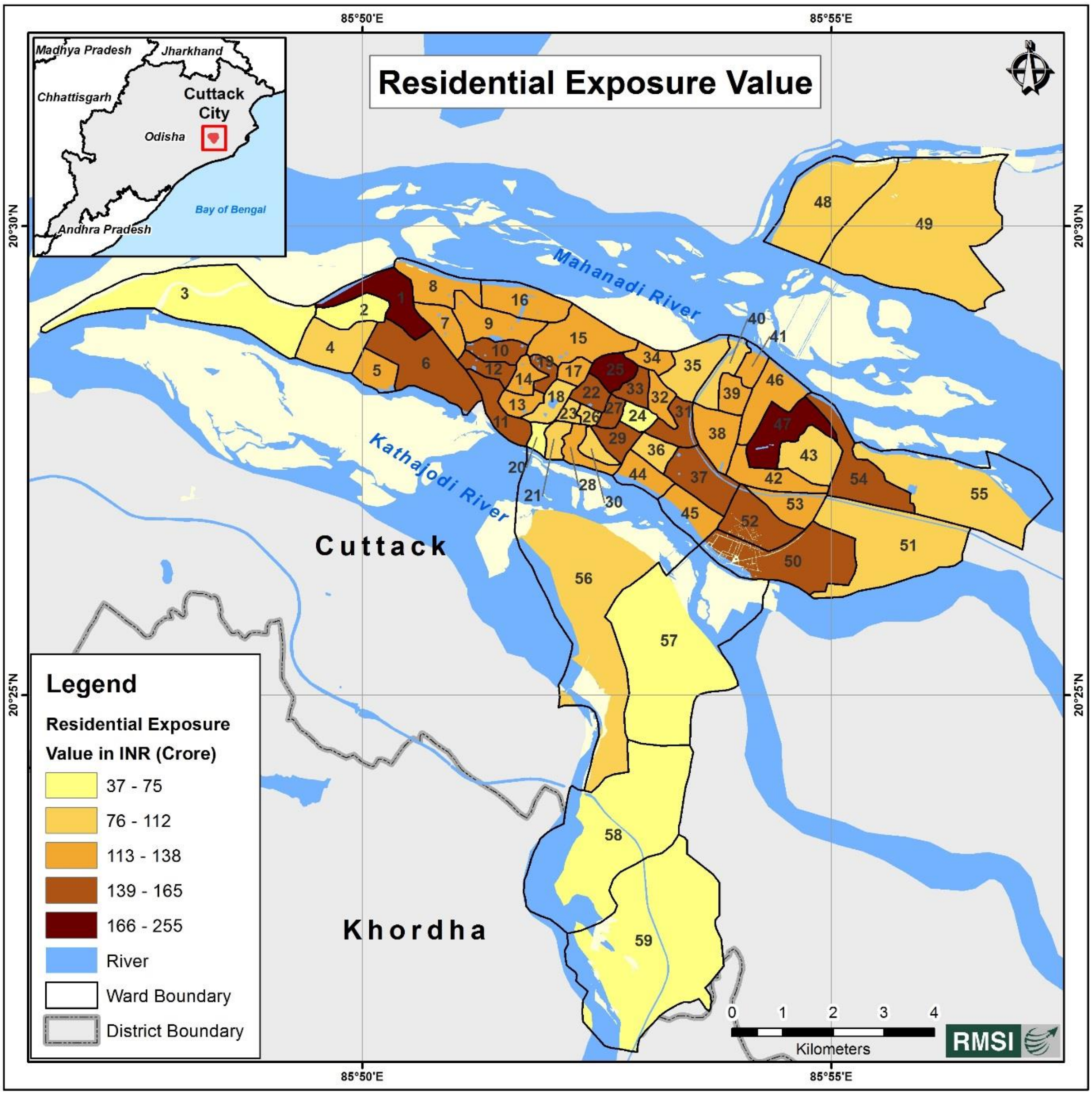

Figure 3-23: Distribution of total estimated exposure values for residential buildings at ward level

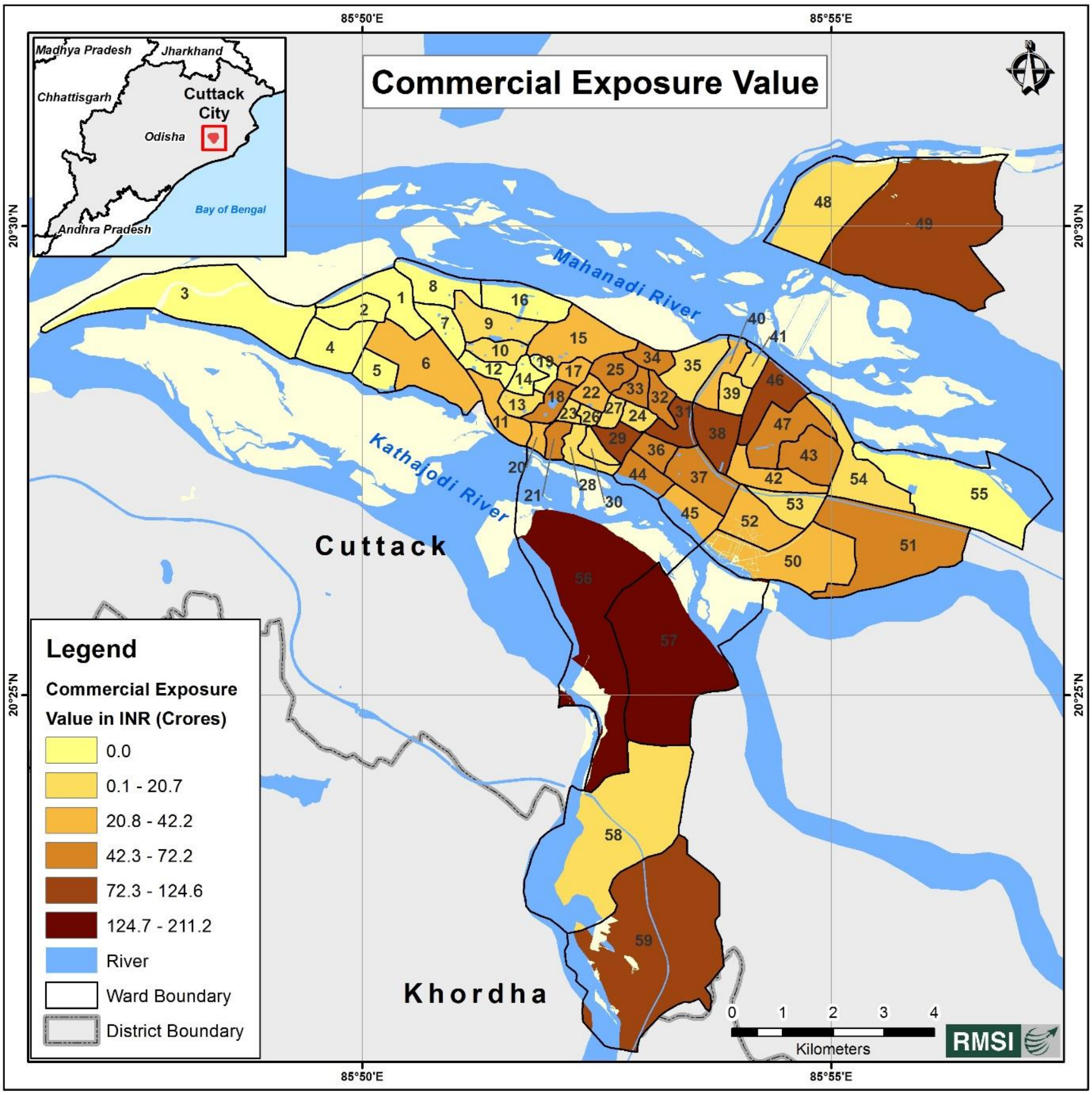

Figure 3-24: Distribution of total estimated exposure values for commercial buildings at ward level

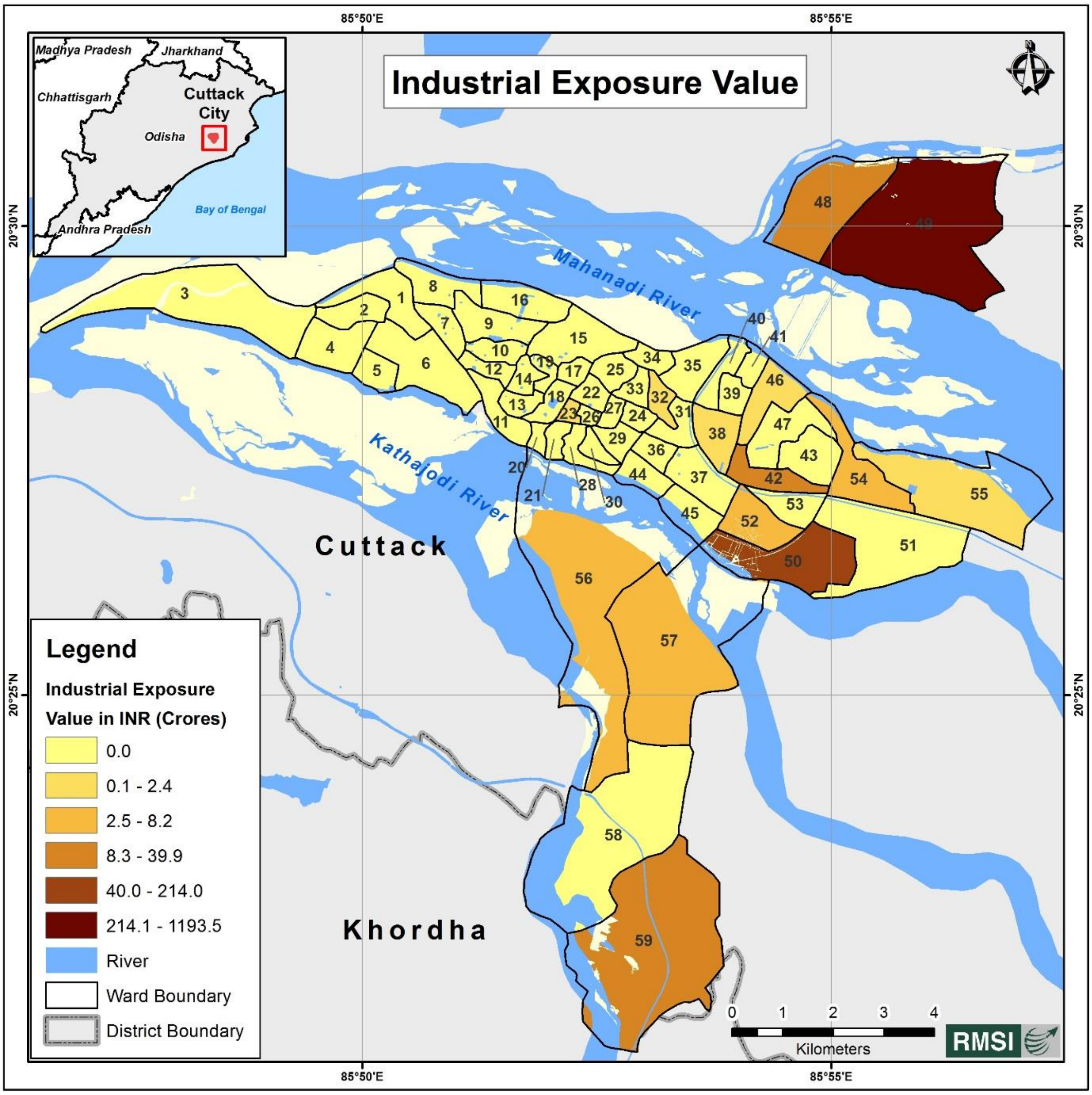

Figure 3-25: Distribution of total estimated exposure values for industrial buildings at ward level.

4 Component 3: Vulnerability Assessment

UNISDR defines vulnerability as "the characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard." There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset), which is independent of its exposure. However, in common use, the word is often used more broadly to include the elements of exposure (http://www.unisdr.org/we/inform/terminology).

In other words, vulnerability is the inability to resist a hazard or to respond when a disaster has occurred. In fact, vulnerability depends on several factors, such as people's age and state of health, local environmental and sanitary conditions, as well as on the quality and state of buildings and their locations with respect to any hazard.

Families with low incomes often live in high-risk areas in the cities, because they cannot afford to live in safer (which are often more expensive) places. Structural vulnerability varies from disaster to disaster. A wooden house is sometimes less likely to collapse in an earthquake, but it may be more vulnerable in the event of a fire or a strong wind.

4.1 Physical Vulnerability

4.1.1 Rapid Visual Screening (RVS) Analysis

RVS is a quick way of assessing building vulnerability based on visual screening. Evaluation in this first level does not require any structural testing. The RVS methodology is referred to as a *sidewalk survey*, in which an experienced screener visually examines a building to identify features that affect the seismic performance of the building, such as building type, seismicity, soil conditions, and irregularities. The visual survey of a building can be completed in about 30 minutes and can be accomplished from the street without entering a building. This survey is carried out based on the pre-defined, field tested checklist. A performance score is calculated for each building based on numerical values on the RVS checklist corresponding to the features of the building. This performance score mainly depends on soil type, building condition, and architectural and earthquake resistant features. Other important data regarding the building is also gathered during the screening, including the occupancy of the building and the presence of nonstructural falling hazards. In this, nonstructural interior components are not evaluated. The performance score is compared to a "*cut-off*" score to determine whether a building has potential vulnerabilities that should be evaluated further by an experienced engineer. From these scores, we can come to a conclusion on whether the building strength is adequate for earthquake forces likely to occur at the site.

The city RVS survey data shows diverse variety of building materials are being used for construction of buildings. The buildings in this city are mostly low to medium rise. For the survey purpose, these buildings are classified based on use as residential, commercial, and mixed type. In the case of masonry buildings, all the buildings in the area have three stories or less.

In the case of RCC buildings, the buildings in the city are below 8 stories. It was observed that the apparent quality of construction of RCC buildings are reasonably good. Very few buildings have heavy overhangs. A significant number of buildings have vertical irregularities (presence of setbacks). Eighty-one percent of buildings are constructed on alluvium soil and 19% are constructed on moderate deep soil. It was also observed that a significant number of buildings did not have full access. About 68% of total buildings had partial access and only 32% of total buildings have full access.

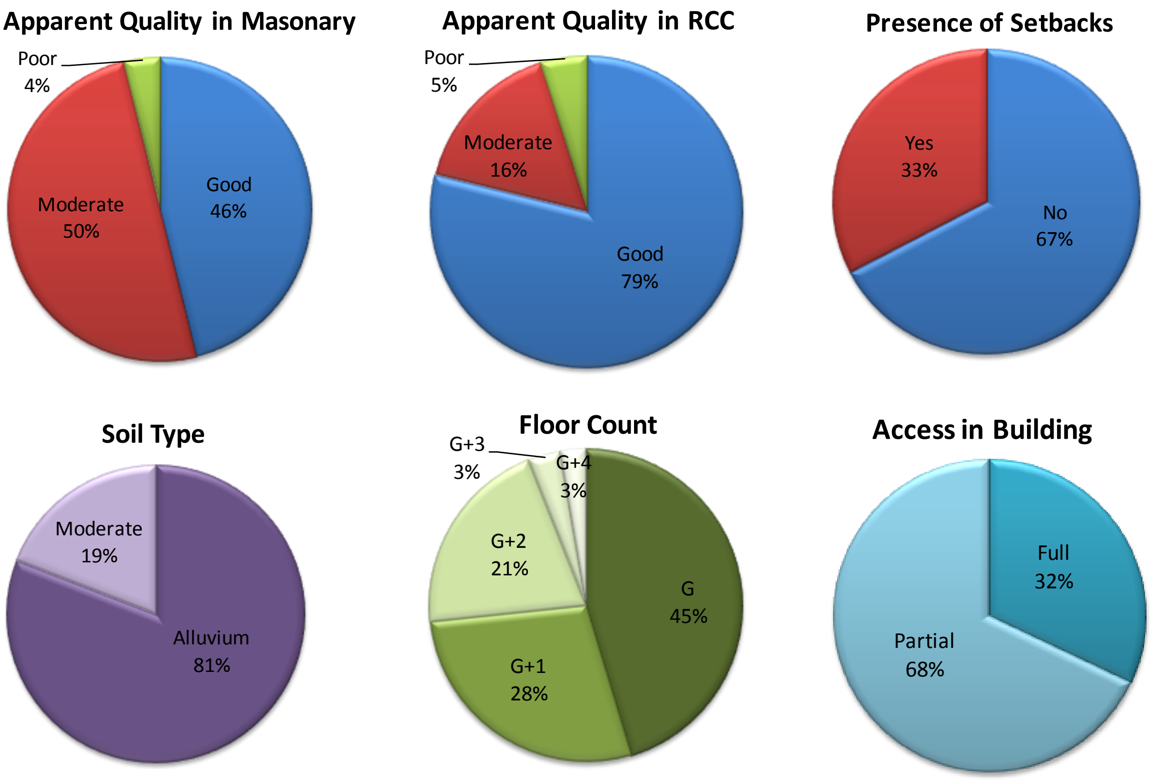

Figure 4-1: Statistics of structural and physical information of sample surveyed

The building with low score on RVS survey needs to be further investigated by structural expert. Based on a detailed inspection, engineering analyses, and other detailed procedures, a final determination of the seismic protection adequacy and the need for retrofitting can be recommended. Typically, an evaluation based on ASCE/SEI 41-13, Seismic Evaluation and Retrofit of Existing Buildings (ASCE, 2014), will be most appropriate for those buildings that require a detailed structural evaluation.

It appears that most of the buildings are not well-designed and the average performance scores are lower than the base score. Buildings given in the list may need further detailed investigation.

Table 4-1: Some Sample buildings that need additional investigation

Ward No.	Building use	Address	Photo
22	Commercial building (Masonry)	Shiv Bazar, Rasua Patna	

Ward No.	Building use	Address	Photo
34	Commercial building (Masonry)	Mangla Bag	
48	Commercial building (Masonry)	Najarpur	
49	Industrial building (Masonry)	Utkal Galvanizer Ltd., Industrial Estate	
50	Industrial building (Masonry)	Jaganath Road, Nuapada	

Ward No.	Building use	Address	Photo
50	Industrial building (Masonry)	Jaganath Road, Nuapada	
52	Industrial building	Ruchi Company, Industrial Estate	

To improve resilience to hazards, it is critical for the city to strictly follow the building codes and develop controls. The city needs to opt for decongesting the overcrowded city center by regulating new permissions for construction and encouraging construction on the outskirts by giving incentives. There is a possibility for vertical expansion in the city center but these efforts need to strictly follow structural norms to ensure they are resilient to the hazards in the region.

4.1.2 SOCIAL VULNERABILITY ASSESSMENT

4.1.2.1 Population profiling and identifying vulnerable groups

The city has a population density of 7,823 per sq. km. The city has an area of about 78 sq. km, which is higher than that of Bhubaneswar city. The rate of population growth is at a decreasing pace compared to past decades and is below the state average (Figure 4-2).

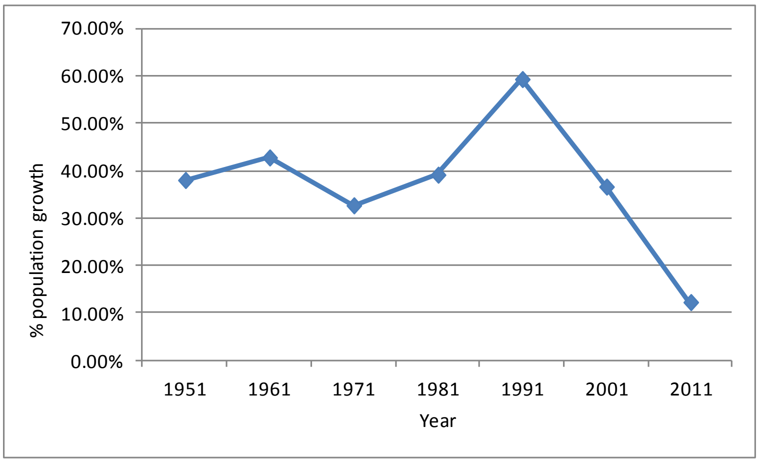

Figure 4-2:Decadal population growth rate (1951-2011)

About 21% of the population is of age groups <6 and >60 and 13% are SC and ST population. The average household size of Cuttack city is 4.7 people per household.

The city has 309 slums pockets (Cuttack Municipality, 2017[3]) spread across the city with a total population of 235,980 (Census 2011) constituting 40% of the total population. Of the 309 slum pockets, 200 are authorized, 104 are unauthorized, and 5 are tenants (Cuttack Municipality, 2017). These pockets are small and dispersed across the city but a majority of them are in the central island (referred to as the Central Millennium City in the CDP document) which is the core city area. The distribution of slum locations in the city is shown in Figure 4-3. The growth of slums in the city is restrained by space and geographical conditions of the city. The slum population lives in poor structures even though many of these slums have electricity and water supply from the municipality. The household size of slum dwellings is smaller (average family size is 4 per household) compared to that of the city figure. Mostly, the slum dwellers are migrants from rural parts of Odisha and neighboring states and contribute a major share to the work force (mostly casual laborers) including street vendors, domestic support, casual workers, and laborers in industries.

[3] Cuttack Municipality, 2012, Cuttack Municipality Office.

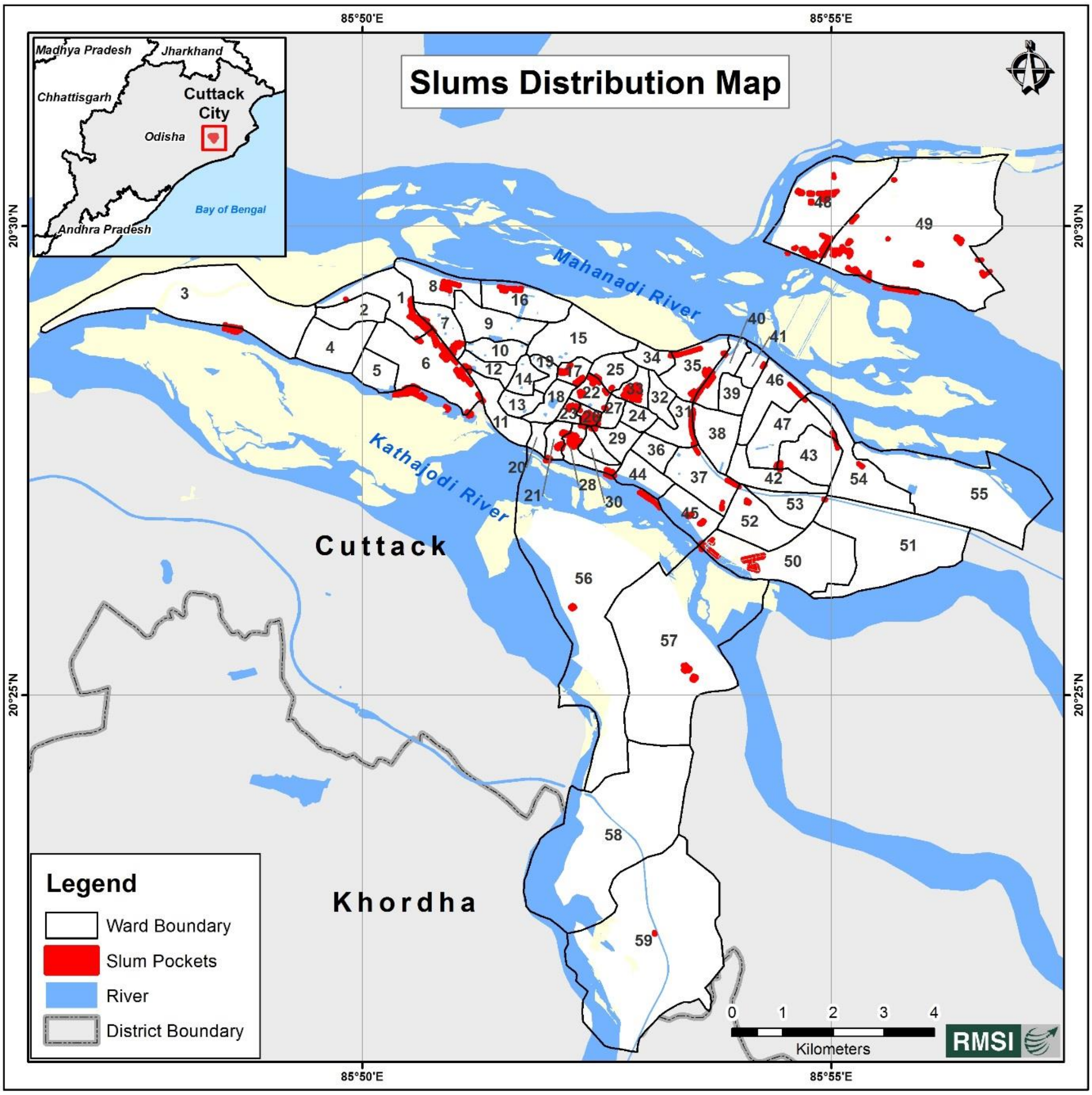

Figure 4-3: Distribution of slums in Cuttack city

Source: Data compiled from CMC

4.1.2.2 Social Vulnerability Analysis

The ward level SoVI is presented in Figure 4-4. The social vulnerability is high specifically in wards, which have a high population density and high population of dependents.

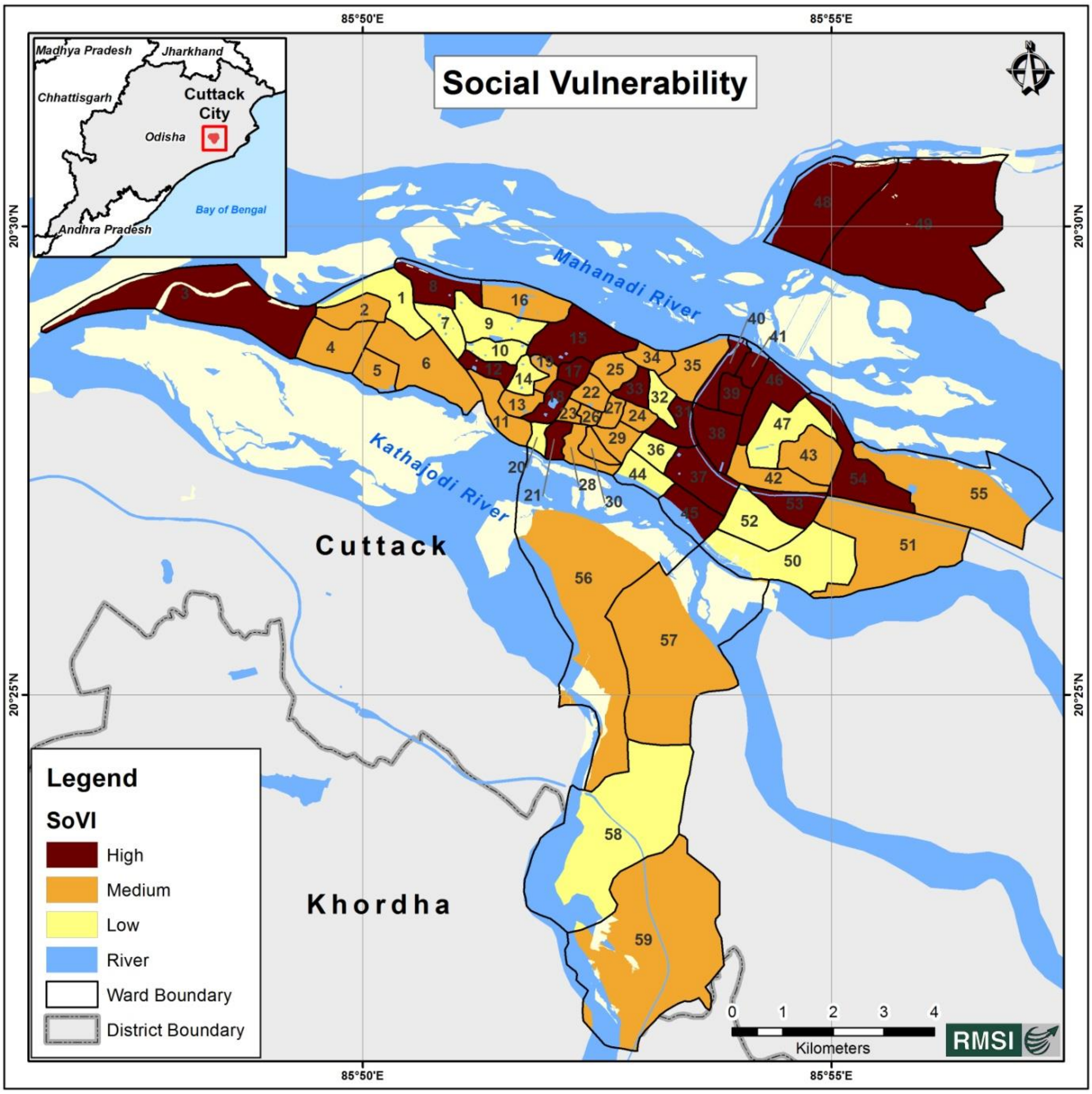

Figure 4-4: Social vulnerability index for Cuttack city

As per the household survey at selected locations, a large number of the households depend on casual work for their livelihood. Figure 4-5 shows the composition of means of livelihood in the sample surveyed. As per the city administration one-third of the city population is street vendors, which is the main source of their livelihood.

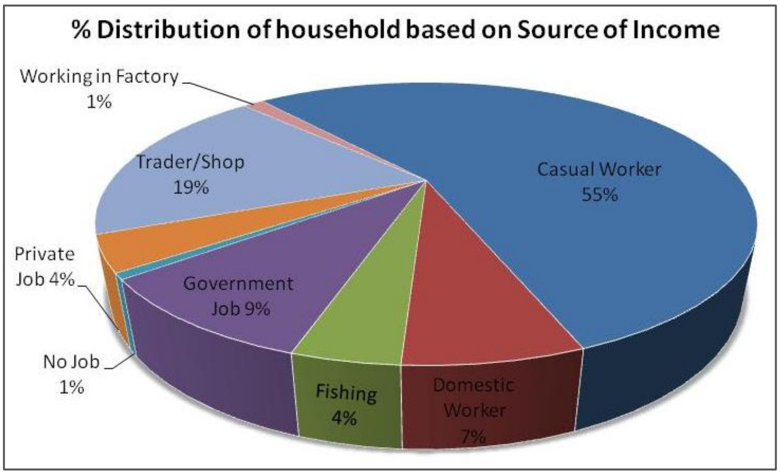

Figure 4-5: Source of income (livelihood) based on occupation, sample survey 2017

The sample also confirms that trade and trade related activities are the key source of livelihood. Casual workers and traders constitute the major share, followed by government jobs. About 50% are casual workers who have a monthly earning ranging between INR 2,000-5,000, 29% are in the range of INR 5,000-10,000 and the rest are above INR 10,000. Apart from these, those in government jobs and traders are the only groups that are earning about INR 10,000 per month. Almost 70% of the households have only one income-earning member in the family.

Being an old city, majority of the city dwellers are living in ancestral houses or owned house (74%) and own land. Most of the slums are located on public land that has been encroached upon and the survey sample also has 23% of city dwellers living in public owned land.

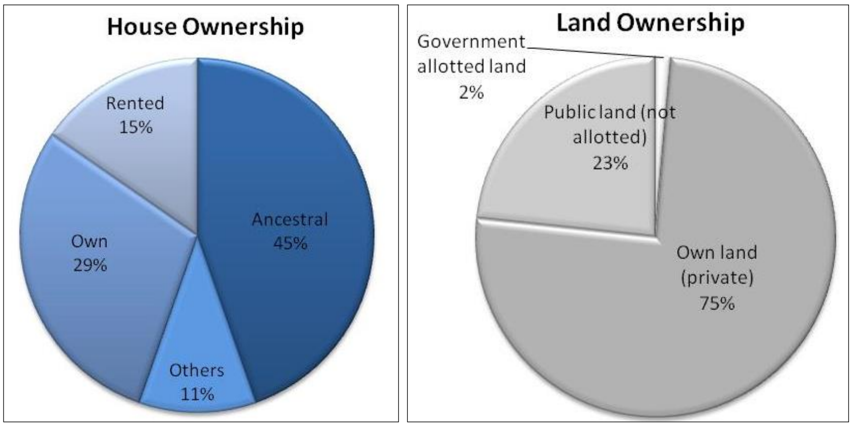

Figure 4-6: House and land ownership

The city has a reasonably good standard of basic service facilities – piped drinking water and electricity. However, most parts of the city have narrow roads, and poor drains and sewer systems. Under different developmental projects, the city is now extending safe drinking water and sewerage system across the city. However, the implementation of these projects is facing problems, including poor coordination and delays, leading to inconvenience for the people. For instance, in Feb 2017, there was a major outbreak of jaundice with 97 reported cases and was caused due to the mixing of sewerage water with drinking water while carrying out construction work of the sewer system.

The city has poor documentation of disease incidence data and the cases reported at government health centers are recorded manually and maintained as hard copies without location details (ward number). Cases reported at private hospitals and clinics stay in isolation. Even though Cuttack city is also covered under the National Urban Health Mission (NUHM) and has initiated several initiatives in the city (including outsourcing operation of an urban unit to a private agency), there is no initiative to systematically document and maintain a centralized database on disease incidence. It is important to understand the locations and months of the year when there is high incidence of diseases particularly water borne and vector borne diseases to take proactive measures ahead of time to reduce the impact. Based on the four years of disease data provided by CMC, the following inferences can be made. Figure 4-7 shows the reported dengue and jaundice cases in the last four years in the city at city hospital. This data shows a decreasing trend. There are a couple of instances where some wards have a large number of reported cases; for instance, in 2013 wards 21, 23, and 30 reported 110, 249, and 68 dengue cases respectively. In 2016, 147 cases were reported in ward 49. Similarly, in 2015, 33 and 34 cases of jaundice were reported in wards 23 and 25 respectively, 38 cases in ward 33 in 2015, and 97 cases in ward 8 in 2017. Interestingly, the city records do not have information on diarrhea, which is a common disease in the city.

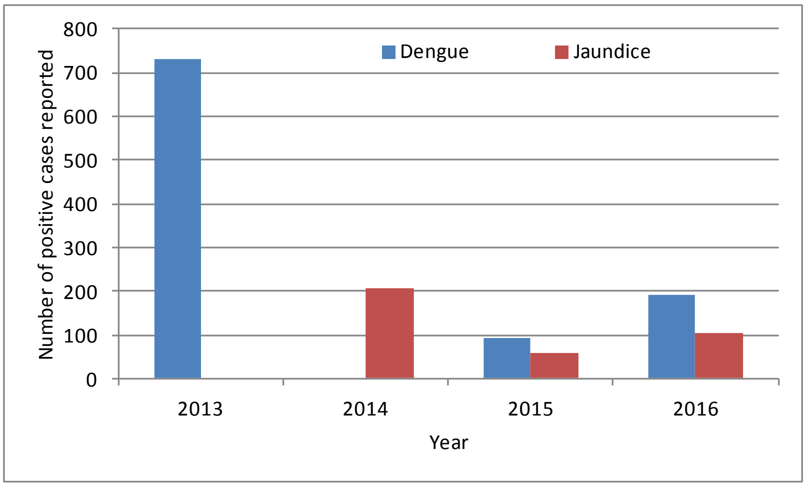

Figure 4-7: Reported cases of dengue and jaundice in Cuttack in last four years

Source: CMC, 2017

The household survey (Figure 4-8) shows that malaria cases are also reported in the city. Even though no trend can be mapped with 4 years of data, it should be noted that the city needs attention to reduce the impact of waterborne and vector borne diseases.

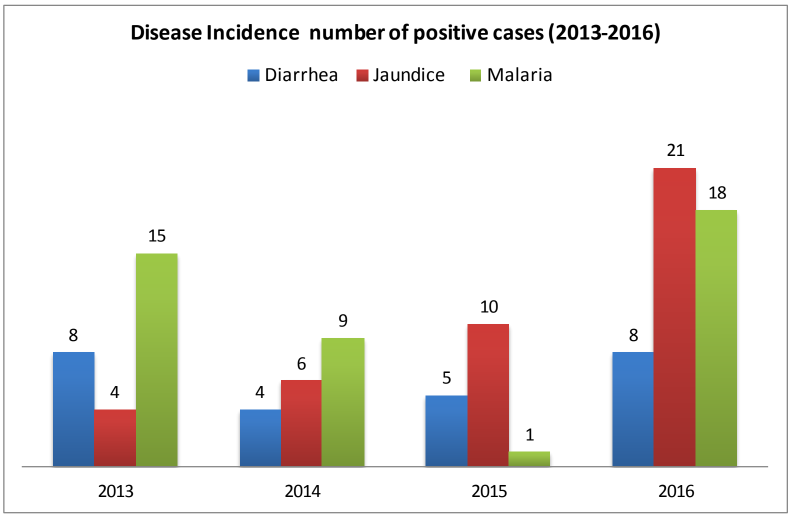

Figure 4-8: Disease incidence as per household survey

In terms of hazards, cyclone hazard seems to affect the community more than other hazards. Even though flood and water logging affect the city causing inconvenience and economic losses, the community is more concerned about the damages caused due to cyclones. All the 10 sample wards surveyed reported that they were impacted by cyclones while wards 4, 5, 9, 15, 16, and 46 reported impact due to floods. The economic losses due to cyclone damage to houses and assets are also high. The economic losses from cyclones was 20 times more than that for flood as per the survey respondents. The economic losses due to cyclones during the recent past is provided in Figure 4-9. The 1999 Super Cyclone affected the city most. Interestingly, cyclones have affected the city in the last 4 consecutive years. Like many other cities, there are pockets vulnerable to floods, including locations between the embankments and the river along the ring road, where communities are living.

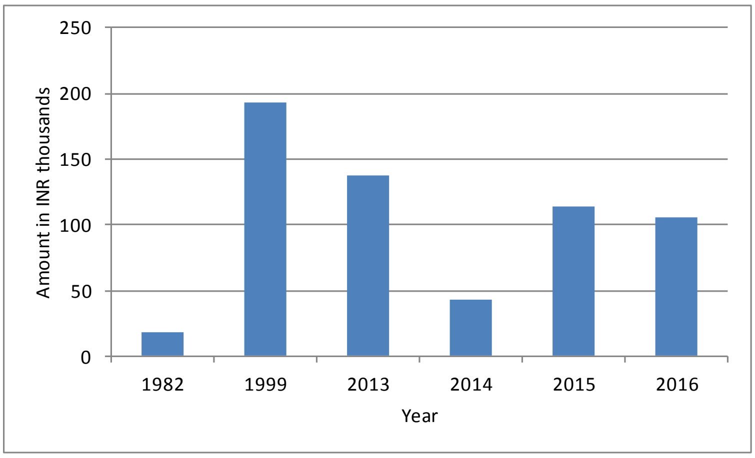

Figure 4-9: Economic losses due to cyclones in the recent past as per the household survey

In terms of early warning and response, the city has good facilities including identified shelter locations.

4.1.3 Economic Vulnerability Assessment

Economic vulnerability can be directly linked to the livelihood aspect of the community. For livelihood impact assessment, data related to socio economic aspects, key occupations the community depends upon for livelihood, and the nature of hazards affecting the city were considered. The FAO framework considers livelihood assets and activities, vulnerability and coping strategies, policies, institutions and processes and livelihood outcomes. This framework is mainly for three levels of assessment when a region is affected by disaster – for quick assistance, to develop short and medium term livelihood strategies, and for medium and long-term sectoral intervention programs.

However, in the present case, our objective is to understand the sectoral impact to guide city administrators to undertake short and medium term livelihood strategies to improve economic resilience and thus improve social resilience. For this, we mainly focus on the first component of the framework - livelihood assets and activities. Livelihood assets are mainly of five categories: natural resources (also called ‘natural capital’), physical reproducible goods (‘physical capital’), monetary resources (‘financial capital’), human power with different skills (‘human capital’), and social networks of various kinds (‘social capital’). In the case of the city, natural capital influences the least while monetary resources and human power influence the most.

Cuttack’s economy is heavily driven by its traditional trade related activities - textiles and handicrafts along with a wide array of industries ranging from steel, ferrous alloys and logistics to agriculture. The city is the second-largest hub for textiles in eastern India, after Raipur and is supposed to have the largest GDP among all the cities in Odisha.

As the city act as a hub for trade and commerce activities, impact of hazard can affect a larger economy as there will be business interruption. The city has poor infrastructure facilities within the city, even though is well-connected with rest of the state. The business operation of the city is unique with having production centers operating outside the state and doing distribution from the city. The reason for the city still holding prominence in trade in the State is because trade has been passed down for generations and these traditional traders don't want to relocate even if there are better infrastructure facilities available in the adjacent area. As per a RMSI report published in 2014[4], a 4-day wage-loss for 40% of the working population in the city in the case of a cyclone event would cause an economic loss of about INR 5 crores. In case of floods and heavy rains, 10-days of work-interruption for 40% of the working population could cause a wage loss of INR 13 crores for the city.

To improve the economic resilience of the city, the following need to be considered:

1. Encourage or enforce the digital drive and emphasize on e-commerce activities in the trade sector of the city
2. Improve infrastructure, particularly roads and buildings in the wards which have a concentration of trade activities
3. Give incentives to traders to start business activities outside the core city area and impose disincentives like increased floor taxes for trade activities in the core city area to regulate the density of shops in the core city area
4. Plan spatial growth considering the growth pockets of the city, particularly in the city outskirts
5. Good governance and improved service delivery, and influence in regional policy formulation can influence the growth of the city on the economic front. City governance should be responsive towards the business requirements of the economic sectors of the city.

4.1.4 Environmental vulnerability

The recent past has witnessed the city's expansion both in terms of vertical and horizontal growth, beyond its main island, especially towards the south and northeast directions. Traditionally, the masonry houses of the city are multi storied though the community still does not prefer to go for multi storied apartments. This has stimulated the horizontal growth of the city beyond the main island. The spatial growth trend of the built-up area of the city over the last 40 years captured from satellite images is presented in Figure 4-10.

[4] RMSI 2014, Towards Climate Resilient and Carbon Conscious Growth in Odisha: NLTA to Support Implementation of Odisha State Climate Change Action Plan, The World Bank.

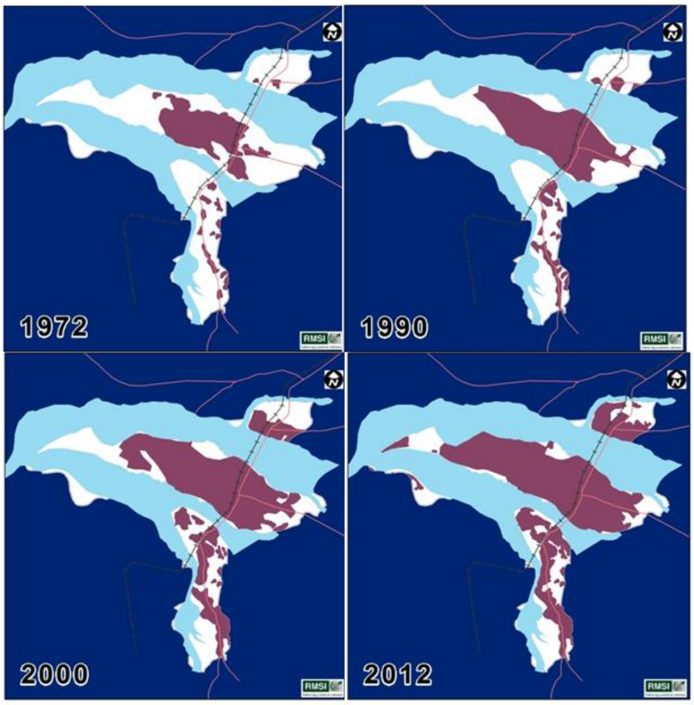

Figure 4-10: Urban growth in Cuttack city over the last 40 years

Data source: RMSI 2014[5]

The development, mainly residential development, is along the main roads – NH 5 towards Bhubaneswar, Cuttack-Baral road, and NH 5 towards Jajatpur. Interestingly, there is relatively less development towards the Cuttack-Paradip road. The built-up footprint of the city (Figure 4-10) shows that the main island reached saturation in year 2000 and the pace of growth has now spilled beyond this island. The 2012 built-up footprint shows the growth of the city extending towards the northeast and south beyond the main island.

Pockets of environmental vulnerability: The low-lying areas of the city, particularly the main island, are vulnerable to environmental and health issues due to overcrowding and choked drains that cause water logging and unhygienic conditions. The poor environmental conditions often trigger epidemics particularly related to water-borne and vector borne diseases.

In addition to this, new residential development on the southern fringe of the city is mainly on reclaimed low-lying areas, which can cause water logging and urban flash floods unless proper drainage is planned.

[5] RMSI 2014, Towards Climate Resilient and Carbon Conscious Growth in Odisha: NLTA to Support Implementation of Odisha State Climate Change Action Plan, The World Bank.

5 Component 4: Risk Assessment

Risk is the uncertainty of future losses – if we perfectly know a future loss, it is simply a cost, not a risk. Risk is uncertain with regard to the causative hazard event (e.g. cyclonic wind, earthquake, flood, etc.), and its location, date and time of occurrence, and the degree or amount of damage to assets caused by the hazard event, and what losses accrue due to the damage.

Since risks are uncertain, they must be stated probabilistically as shown in Figure 5-1, which is expressed in terms of a Loss Exceedance Curve (LEC, also sometimes termed an Exceedance Probability, or EP curve).

The abscissa of the LEC is loss, while the ordinate is the frequency or probability of loss (for most losses, probability and frequency are equivalent). Small losses occur frequently, and large losses rarely, so the curve slopes downward to the right. The probability weighted average of all possible losses is termed the Average Annual Loss, or AAL. AAL is equivalent to the average per year of all future losses. In this study, losses are presented in terms of AAL and LECs, with emphasis on some key points on the LEC, such as the “25-year loss” or the “100 year loss”. By “25 year loss” we mean a loss that will occur on average about once every 25 years, given what we know about hazards, exposure etc. Such a “25-year loss” in actuality has a 1/25 = 0.04 probability of occurrence in any one year. Similarly, a “100-year loss” has probability per year (or “per annum”, pa) of 1/100 = 0.001.

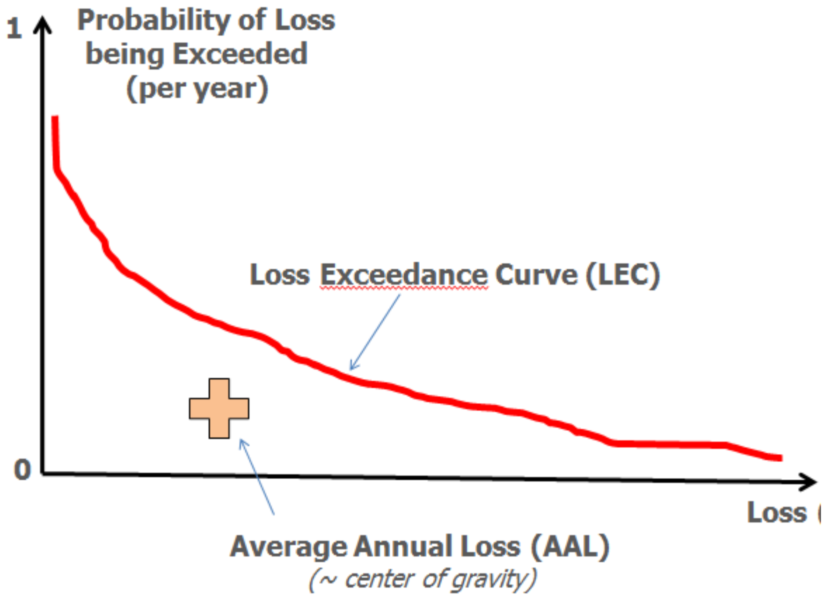

Figure 5-1: Loss Exceedance Curve

5.1 Risk Matrix by Hazard

This section presents an estimate of the losses attributable to each hazard. The findings can be used by the City administration in understanding the potential impacts of each hazard and allowing a comparison of hazards by quantified potential impacts. The loss and damage estimates provided in this section have been developed using available data and the risk assessment methodology that includes the following steps:

- Hazard profiles which include determining the spatial extent of hazards, where possible (i.e., maps), and in understanding the frequency or probability of future events and their magnitude
- Characterization of exposure, which provides a summary of the inventory of assets (buildings - residential, commercial, industrial; and infrastructure), specifically their values. Exposure calculations are carried out by characterizing buildings and

infrastructures and approximation of sizes of the buildings (expressed in square meters), including utilization of satellite imagery and fieldwork

- Vulnerability Assessment, which facilitates an understanding of the built environment's potential performance to different levels of hazard intensity (i.e., wind velocity, peak ground acceleration, flood depth, etc.);
- Impact, loss and damage estimates, which facilitate a quick understanding of the potential impacts or consequences of hazards and the respective economic losses for each hazard, which are calculated using factors described above.

The application of these methodologies results in an approximation of risk. These estimates can be used to understand relative risks from hazards and potential losses. However, it is important to understand that uncertainties are inherent in any loss estimation methodology, arising from approximations and simplifications that are necessary for a comprehensive analysis.

The economic loss and damage results are presented here using three risk indicators:

Probable Maximum Loss (PML), which provides an estimate of losses that are likely to occur, considering existing mitigation features, due to a single hazard scenario event with one key return-period or with several return-periods;

Loss Exceedance Curve (LEC), which plots the consequences (losses) against the probability for different scenario events with different return periods; and

Average Annualized Loss (AAL), which is the estimated long-term value of losses to assets in any single year within the study area. By annualizing estimated losses, we understand historic patterns of frequent and smaller events as well as patterns with infrequent but larger events, to provide a balanced assessment of risk. The AAL is the summation of products of event losses and event occurrence probabilities for all stochastic events in a loss model and is expressed as:

Average Annual Losses = $\sum_i P_i L_i$

The use of the annualized losses approach has two primary benefits, including: the ability to assess potential losses from all future disasters; and providing an objective means to evaluate risk mitigation alternatives.

The risk metrics (AAL, LEC and Loss Cost) can be used to identify and prioritize the parts of the city that are under risk. In addition, there are certain exposure elements that are critical for emergency response, such as hospitals that needs priority protection.

5.1.1 Cyclonic Wind

After finalizing the hazard data and generation of cyclonic wind hazard maps for Cuttack city, the hazard data has been used for the assessment of damage and risk associated with cyclonic wind hazard. Cyclonic wind hazard associated loss assessment has been carried out based on the frequency and severity of various cyclone events at different return periods ranging from events that are more frequent to rare. For the analysis, the various datasets such as wind speed and extent, exposure, and vulnerability curves have been used to understand the damage and risk. The six key return period scenarios (2, 5, 10, 25, 50 and 100 years) and six climate change scenarios (two each for 25, 50 and 100) have been considered for risk assessment. Before analyzing the losses, the various loss scenarios and terminologies used in the report are explained for the convenience of the reader (Table 5-1).

Table 5-1: Recurrence intervals, probabilities of occurrences, and percentage chance of occurrences

Return period years	Probability of occurrence in a year	Percentage chance of occurrence in a year
2	1 in 2 year	50
5	1 in 5 year	20
10	1 in 10 year	10
25	1 in 25 year	4
50	1 in 50 year	2
100	1 in 100 year	1

5.1.1.1 Estimated Potential Cyclonic Wind Hazard Losses for General Occupancy

The estimates of potential losses due to the cyclonic wind hazard for general occupancy (residential, industrial, and commercial) classes are summarized in Table 5-2. The six annual probabilities of occurrences (50%, 20%, 10%, 4%, 2% and 1%) are used for potential losses estimation.

From Table 5-2, it is clear that PML from cyclonic wind hazard are higher for residential and industrial occupancies as compared to the commercial losses. As expected, the losses for general occupancies are consistently increasing from higher probability of occurrences to lower probability of occurrences events. For 1% annual occurrence of cyclonic wind event, the losses are estimated at about INR 884.96 crores, INR 279.21 crores, and INR 562.65 crores for residential, commercial, and industrial occupancies respectively. The analysis indicates that losses for 1% annual probability are almost twice of 2% annual probability event.

The distribution of potential losses to residential buildings for 15 most affected wards of the Cuttack city is presented in Table 5-3. Table clearly shows that ward numbers 10 and 15 are the most vulnerable wards. The losses are sorted based on high to low frequency of occurrences.

Similarly, Table 5-4 and Table 5-5 summarize the ward wise distribution of potential losses to affected commercial and industrial buildings respectively.

Table 5-2: Potential maximum losses for cyclonic wind hazard in Cuttack city

Probability of occurrence	Estimated potential losses for general occupancies (INR crores)		
	Residential	Commercial	Industrial
50%	1.43	0.46	0.90
20%	15.96	5.06	9.74
10%	54.54	17.27	34.31
4%	195.58	61.52	122.10
2%	436.29	137.64	274.90
1%	884.96	279.21	562.65

Table 5-3: Structural loss matrix corresponds to various annual cyclonic wind probabilities for residential buildings in Cuttack city

Ward No.	Estimated potential losses for 15 most affected wards (INR crores)					
	50%	20%	10%	4%	2%	1%
10	0.032	0.35	1.17	4.18	9.57	19.35
15	0.032	0.35	1.22	4.34	9.53	19.27
22	0.031	0.34	1.19	4.24	9.33	18.85
19	0.030	0.34	1.16	4.15	9.13	18.45
27	0.030	0.34	1.16	4.14	9.12	18.42

Ward No.	Estimated potential losses for 15 most affected wards (INR crores)					
	50%	20%	10%	4%	2%	1%
47	0.029	0.34	1.18	4.18	9.17	19.00
50	0.029	0.34	1.13	4.17	9.15	18.34
26	0.029	0.32	1.12	4.00	8.79	17.77
52	0.029	0.32	1.11	3.96	9.04	18.11
12	0.029	0.32	1.05	3.78	8.66	17.50
49	0.029	0.31	1.10	3.88	8.78	18.08
54	0.028	0.30	1.02	3.63	8.24	16.48
45	0.028	0.31	1.06	3.77	8.30	16.77
28	0.027	0.30	1.01	3.61	8.26	16.69
33	0.027	0.30	1.04	3.71	8.47	16.97

Table 5-4: Structural loss matrix corresponds to various annual cyclonic wind probabilities for commercial buildings in Cuttack city

Ward No.	Estimated potential losses for 15 most affected wards (INR crores)					
	50%	20%	10%	4%	2%	1%
56	0.04	0.48	1.57	5.64	12.44	25.38
57	0.04	0.40	1.37	4.69	10.75	21.73
49	0.03	0.34	1.22	4.32	9.77	20.12
59	0.03	0.26	0.86	2.95	6.58	13.05
38	0.02	0.26	0.89	3.19	7.27	14.57
46	0.02	0.24	0.79	2.91	6.39	13.24
29	0.02	0.20	0.69	2.48	5.45	11.02
51	0.02	0.19	0.64	2.26	5.13	10.25
31	0.02	0.18	0.63	2.23	5.08	10.19
37	0.01	0.15	0.52	1.84	4.19	8.39
47	0.01	0.15	0.51	1.80	3.96	8.20
25	0.01	0.14	0.48	1.72	3.78	7.85
18	0.01	0.13	0.45	1.60	3.65	7.39
32	0.01	0.13	0.46	1.64	3.74	7.50
21	0.01	0.13	0.44	1.56	3.44	7.23

Table 5-5: Structural loss matrix corresponds to various annual cyclonic wind probabilities for industrial buildings in Cuttack city

Ward No.	Estimated potential losses for 15 most affected wards (INR crores)					
	50%	20%	10%	4%	2%	1%
49	0.71	7.57	27.07	95.56	216.32	445.33
50	0.12	1.36	4.45	16.51	36.22	72.59
59	0.02	0.24	0.79	2.71	6.05	12.00
42	0.02	0.24	0.83	3.08	6.76	13.55
48	0.01	0.14	0.50	1.83	4.14	8.26
54	0.00	0.05	0.18	0.63	1.43	2.87
56	0.00	0.04	0.14	0.50	1.11	2.27
57	0.00	0.03	0.11	0.38	0.88	1.78

Ward No.	Estimated potential losses for 15 most affected wards (INR crores)					
	50%	20%	10%	4%	2%	1%
52	0.00	0.03	0.10	0.37	0.84	1.68
38	0.00	0.01	0.05	0.18	0.41	0.82
23	0.00	0.01	0.04	0.14	0.33	0.67
55	0.00	0.01	0.04	0.15	0.32	0.66
32	0.00	0.00	0.01	0.02	0.05	0.10
46	0.00	0.00	0.00	0.02	0.04	0.08

For better understanding the distribution of estimated potential losses for various occupancy classes, spatial maps have been generated for these. Figure 5-2, Figure 5-3, and Figure 5-4 show the ward wise spatial distribution of estimated potential losses for these occupancy classes for cyclonic wind with 1% annual probability of occurrence.

Figure 5-2 clearly shows the high residential building losses in the central part of Cuttack city in ward number 10, 15, 47, 22, 19, 27, 50, and 52. Map also shows significant loss in ward 49 located in northern part of the city.

Figure 5-3 shows the high commercial building losses in the southern part of Cuttack city in ward number 56, 57, 49, 38, 46, and 59. Figure does not show any loss in many wards that are located in western part of the city because of the absence of commercial building in these wards.

Ward wise distribution of estimated potential losses for industrial buildings due to 1% annual probability cyclonic wind is shown in Figure 5-4. The figure shows that there is almost no loss in any ward except ward number 49, 50, 42, 59, 48, 54 and 56.

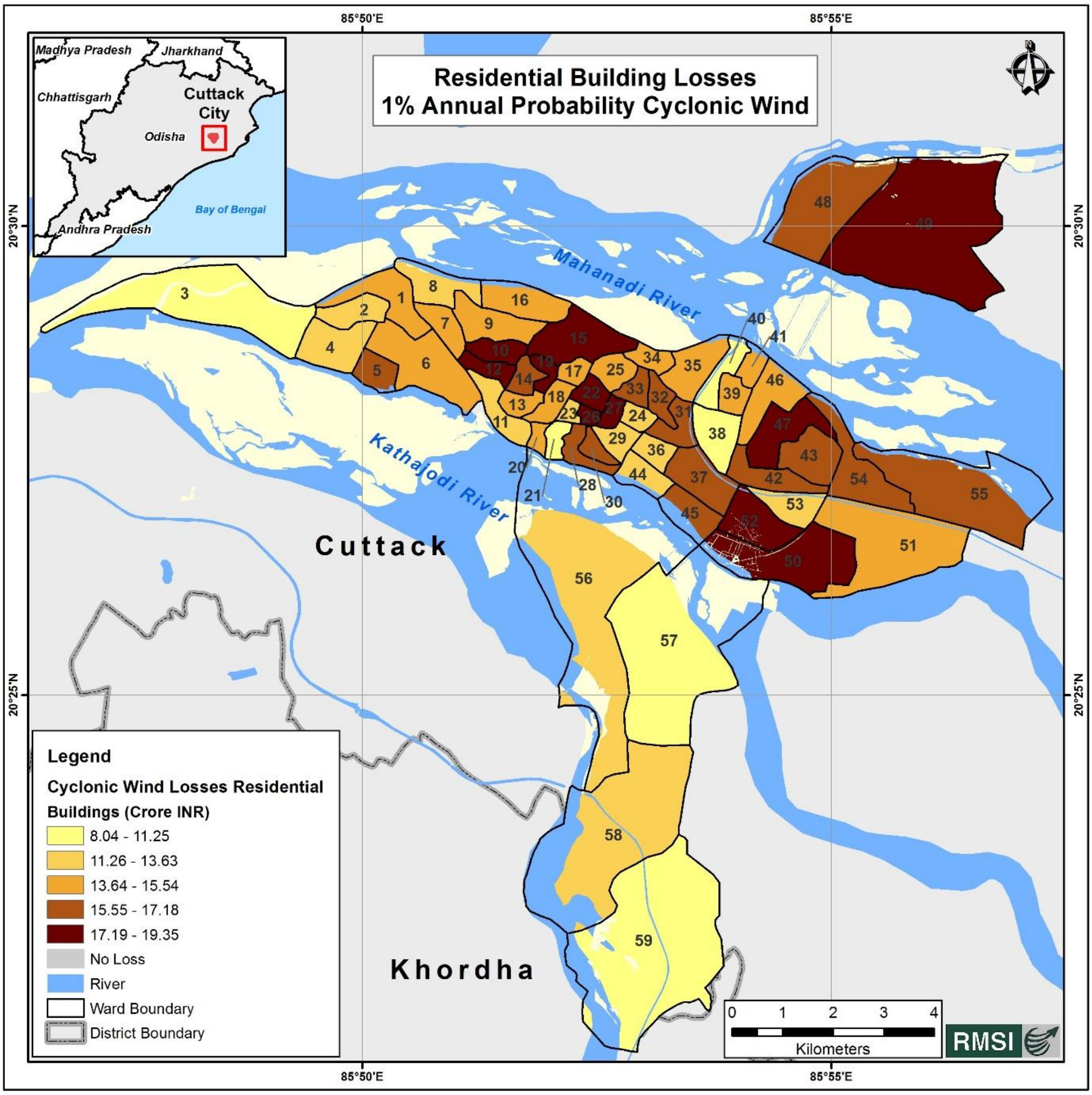

Figure 5-2: Ward wise distribution of estimated potential losses for residential occupancy due to 1% annual probability cyclonic wind

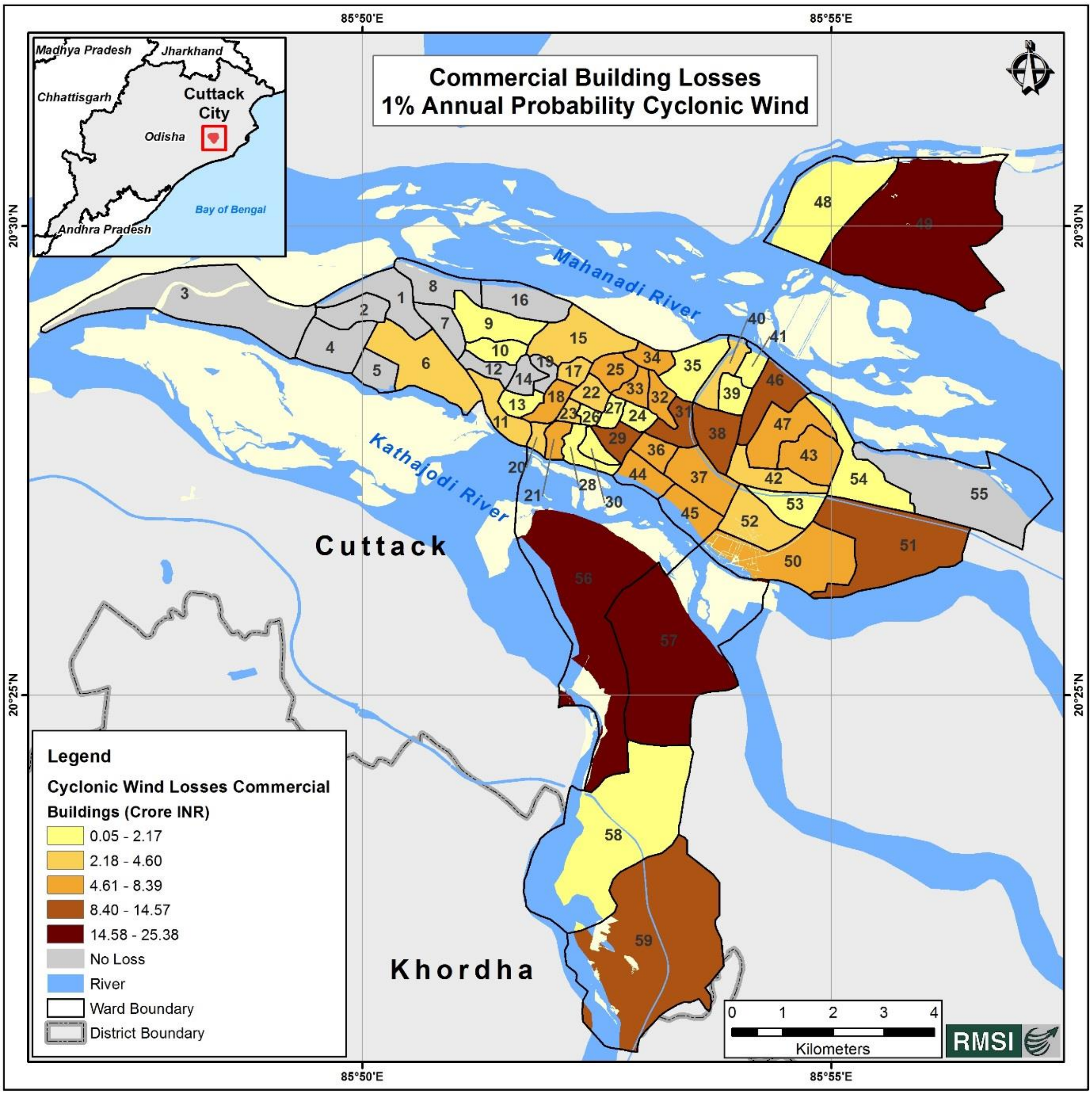

Figure 5-3: Ward wise distribution of estimated potential losses for commercial occupancy due to 1% annual probability cyclonic wind

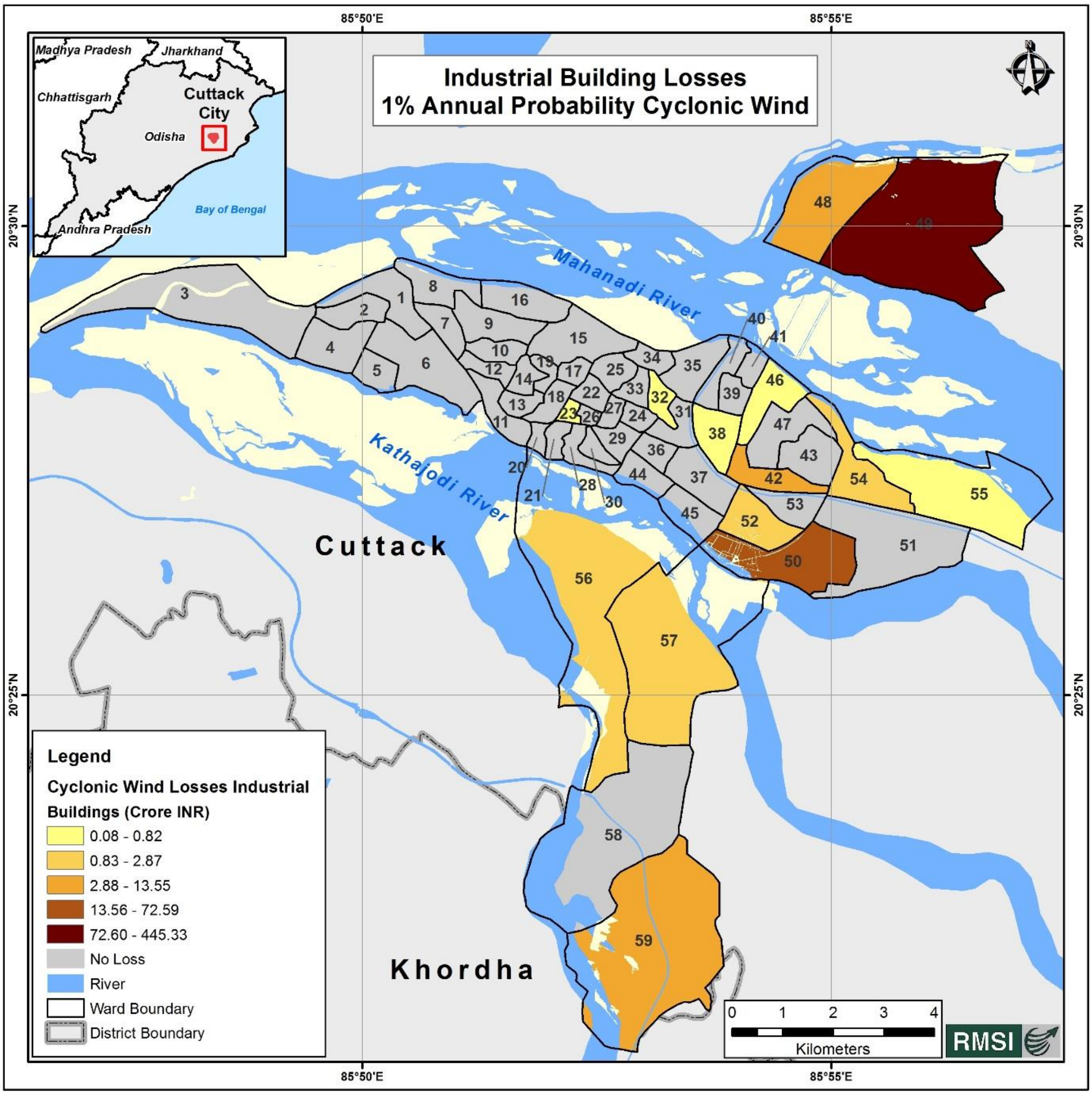

Figure 5-4: Ward wise distribution of estimated potential losses for industrial occupancy due to 1% annual probability cyclonic wind

5.1.1.2 Estimated Potential Cyclonic Wind Hazard Losses to Various Sectors

The potential losses to various sectors have also been estimated. These sectors include transport (roads, railway lines, bridges, and railway stations), utility networks (electricity, communication, portable water, and waste water), and other essential facilities (schools, hospitals, fire stations, police stations, admin headquarters and places of worships) etc.. Table 5-6 summarizes the estimated potential losses to these exposure classes for various annual probabilities of occurrences (50%, 20%, 10%, 4%, 2% and 1%). It is inferred from the table that losses to schools, hospitals, railway stations and the electricity network are significant in the city due to cyclonic winds.

The losses and damages to the transportation structures due to cyclonic wind also contribute significantly in the estimated combined potential losses. It can be seen from the table that estimated potential losses are dominated by railway stations followed by bridge losses. The losses to railway lines and roads are considerable insignificant. Railway station losses are consistently increasing from higher probability of occurrences to the lower probability of occurrences.

Table 5-6: Estimated losses correspond to various annual cyclonic wind probabilities for different exposure utility classes in Cuttack city

Facility/Sectors	Estimated potential Losses in Cuttack city (INR crores)					
	50%	20%	10%	4%	2%	1%
Facilities						
Schools	0.14	1.66	5.62	19.99	44.37	89.69
Hospitals	0.06	0.72	2.44	8.69	19.30	39.01
Religious Places	0.01	0.12	0.40	1.43	3.20	6.48
Admin HQs	0.00	0.00	0.00	0.00	0.00	0.00
Police Stations	0.00	0.00	0.00	0.00	0.00	0.00
Fire Stations	0.00	0.00	0.00	0.00	0.00	0.00
Transport						
Bridges	0.00	0.10	0.39	1.37	3.01	6.09
Railway Lines	0.00	0.02	0.07	0.21	0.46	0.92
Railway Stations	0.03	0.32	1.07	3.96	8.71	18.02
Roads	0.00	0.00	0.07	0.26	0.60	1.23
Utility Networks						
Electricity	0.05	0.51	1.74	6.10	13.63	27.60
Communication	0.00	0.04	0.12	0.43	0.95	1.92
Potable Water	0.00	0.00	0.00	0.00	0.00	0.0
Waste Water	0.00	0.00	0.00	0.00	0.00	0.0

5.1.1.3 Combined Losses, AAL and LEC

Once the potential losses to various exposure classes in the city were estimated, a combined loss matrix was prepared by combining all the expected losses in a ward. Figure 5-6 provides combined estimated potential losses across the various exposure classes corresponding to various annual cyclonic wind probabilities of occurrences. It provides a comparative view across the sector specific losses, which can be useful for administrators and city authorities in taking decisions regarding fund allocations for long-term and short-term strategies.

Figure 5-5 shows the ward wise spatial distribution of combined losses for a probable cyclone event with 1% chances of occurrence annually. Similarly, the combined losses corresponding to 4% and 2% annual probability cyclone events are depicted in Figure 8-40 and Figure 8-41 respectively, in *Annexure-Cyclonic wind Assessment*.

Table 5-7: Combined losses due to cyclonic wind for various annual probabilities in Cuttack city

Exposure Class	Combined losses for various cyclonic wind event scenarios for Cuttack city (INR crores)					
	50%	20%	10%	4%	2%	1%
Residential	1.43	15.96	54.54	195.58	436.29	884.96
Commercial	0.46	5.06	17.27	61.52	137.64	279.21
Industrial	0.90	9.74	34.31	122.10	274.90	562.65
Essential Facilities	0.21	2.54	8.59	30.59	67.92	137.31
Utilities	0.05	0.54	1.86	6.53	14.58	29.52
Transportation Infrastructures	0.03	0.45	1.61	5.80	12.78	26.26

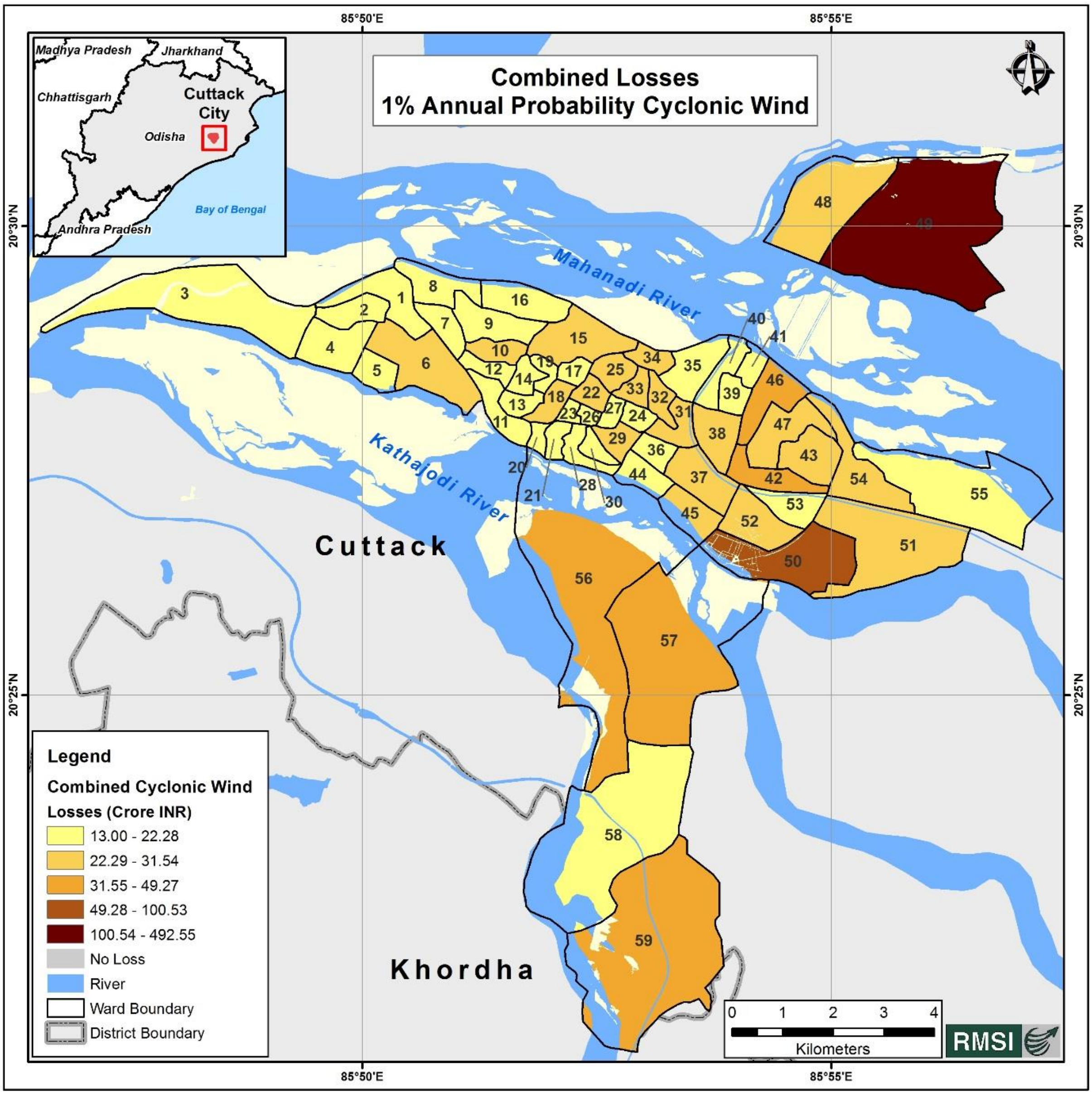

Figure 5-5: Ward wise distribution of estimated combined potential losses for 1% annual probability cyclonic wind

Figure 5-6 shows the map of spatial distribution of ward wise average annualized losses for Cuttack city. The map shows that ward numbers 49 and 50 are most vulnerable as per the combined losses followed by ward numbers 56, 46, 57, 59, and 42. Combined potential losses are predominated mainly by residential and industrial losses.

Table 5-8 provides a comparative distribution of various components contributing to the combined AAL along with AAL as a percentage of the total corresponding value of exposure.

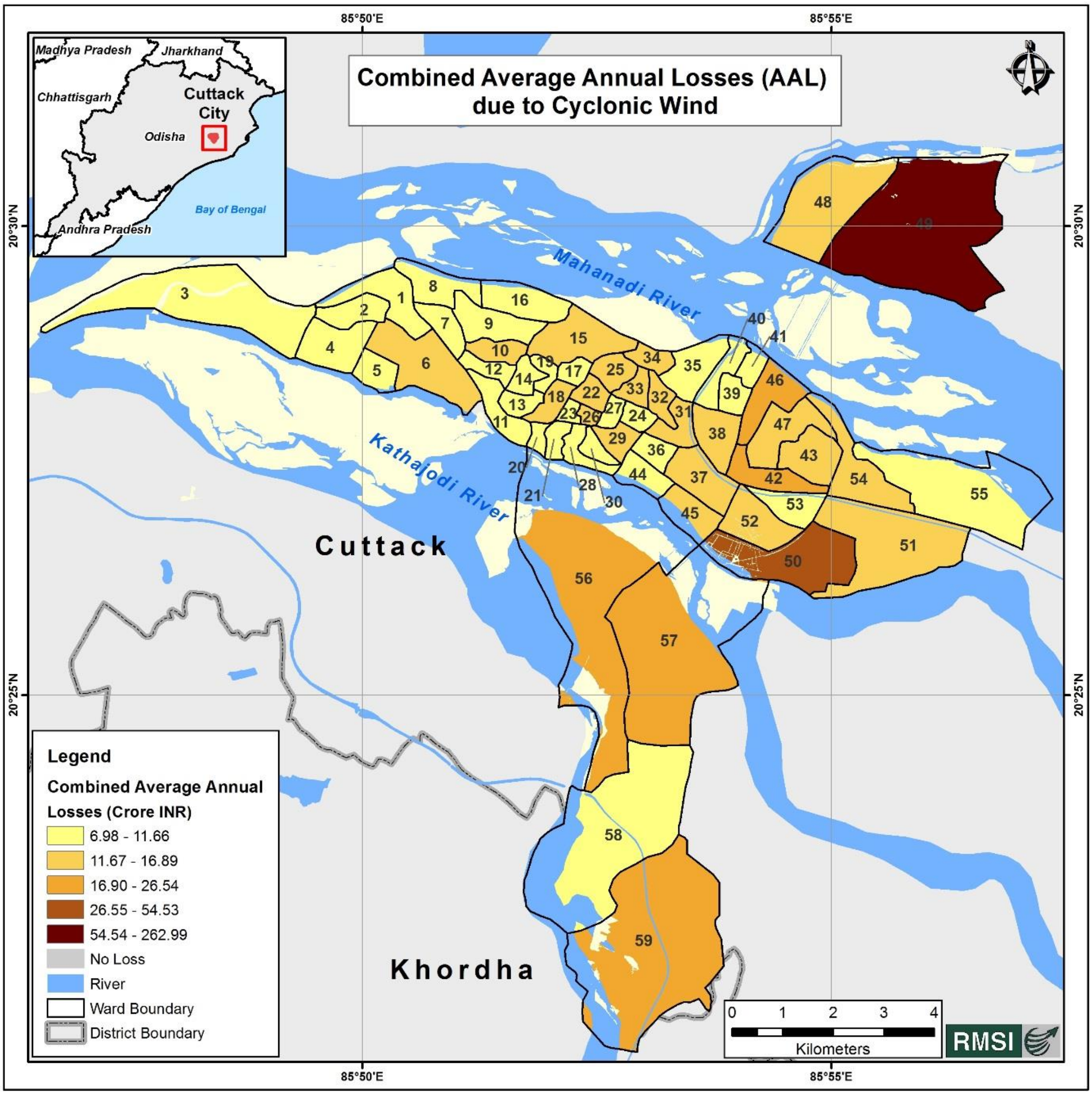

Figure 5-6: Ward wise distribution of average annual loss for Cuttack city

Table 5-8: AALs corresponding to different exposure classes

Exposure Classes	AALs in INR crores	AAL as % of Total Exposure Value
Residential	22.42	0.31
Commercial	7.08	0.3
Industrial	14.12	0.92
Essential Facilities	3.50	0.29
Utilities	0.75	0.13
Transportation Infrastructures	0.66	0.02
Combined	48.53	3.26

LEC curves for various exposure classes, showing a relationship between the estimated potential losses and corresponding probabilities have been plotted in Figure 5-7.

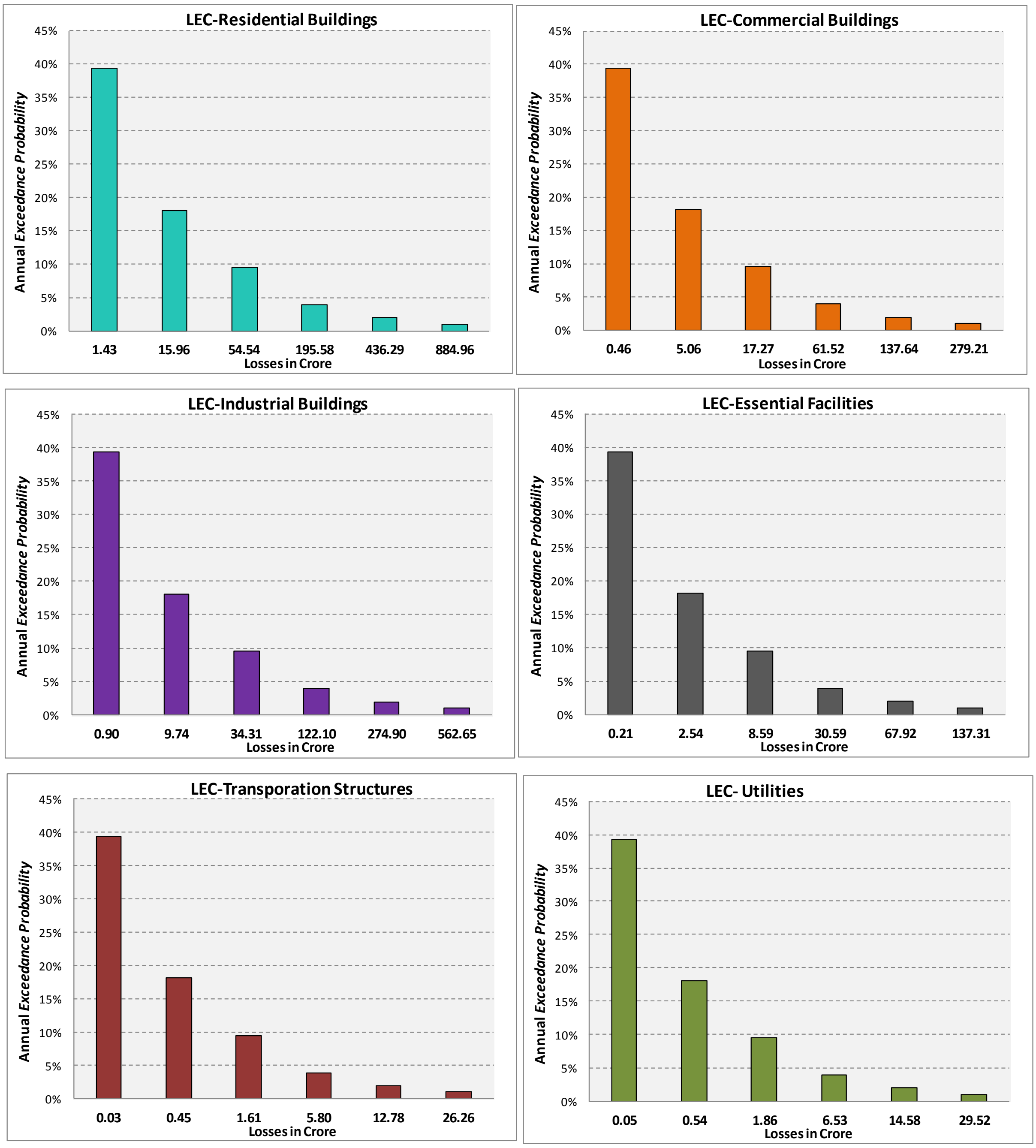

Figure 5-7: LEC for various exposure classes

5.1.1.1 *Estimation of Affected Population and Casualties due to Cyclonic Wind*

For Cyclonic wind, the number of injuries including fatalities is more complex to estimate, as they are a function of cyclone warning time and evacuation planning. If people are evacuated in time, casualties are likely to be significantly lower. Cyclone Phailin and Cyclone Hudhud are recent examples where these numbers were reduced significantly in comparison to similar cyclonic events that occurred in the past and where corresponding number of injuries and fatalities were significantly higher.

5.1.1.2 ***Impact of Climate Change Projections on Cyclonic Wind Losses***

In order to understand the possible impact of projected climate change on cyclonic wind losses, cyclone loss mapping has been carried out. The analysis of climate change projections show that the globally averaged intensity of tropical cyclones will shift towards stronger storms, with intensity increases of 2-11% by 2100. Therefore, to study various climate change scenarios, the cyclone pressure drop was increased by 7% (an average value) and by 11% (extreme value) over the present historical events. From these two climate change scenarios, scenario 1 (7% change) and scenario 2 (11% change) show significant changes to cyclones in future climatic conditions. The potential cyclonic wind losses have been estimated by considering the impact of these climate change scenarios on cyclones.

Table 5-9 shows the increase in cyclonic wind losses due to climate change scenarios on 1%, 2%, and 4% annual occurrences of cyclonic winds.

Table 5-9: Increased losses (%) of climate change on cyclonic wind losses for key cyclonic wind events

Climate Change Scenarios (Increase in pressure drop intensity)	Scenario 1 (7%)	Scenario 2 (11%)
4% Annual occurrence cyclonic wind	25.14%	38.96%
2% Annual occurrence cyclonic wind	26.44%	41.34%
1% Annual occurrence cyclonic wind	27.44%	42.20%

The analysis shows that cyclone losses are expected to significantly increase under the impact of climate change for high occurrence cyclone events. However, for extreme event, such as 1% annual occurrence cyclonic wind, the losses are expected to increase in the range of 27% to 42%. Figure 5-8 and Figure 5-9 show a ward wise spatial distribution of change in cyclonic wind losses for Cuttack city.

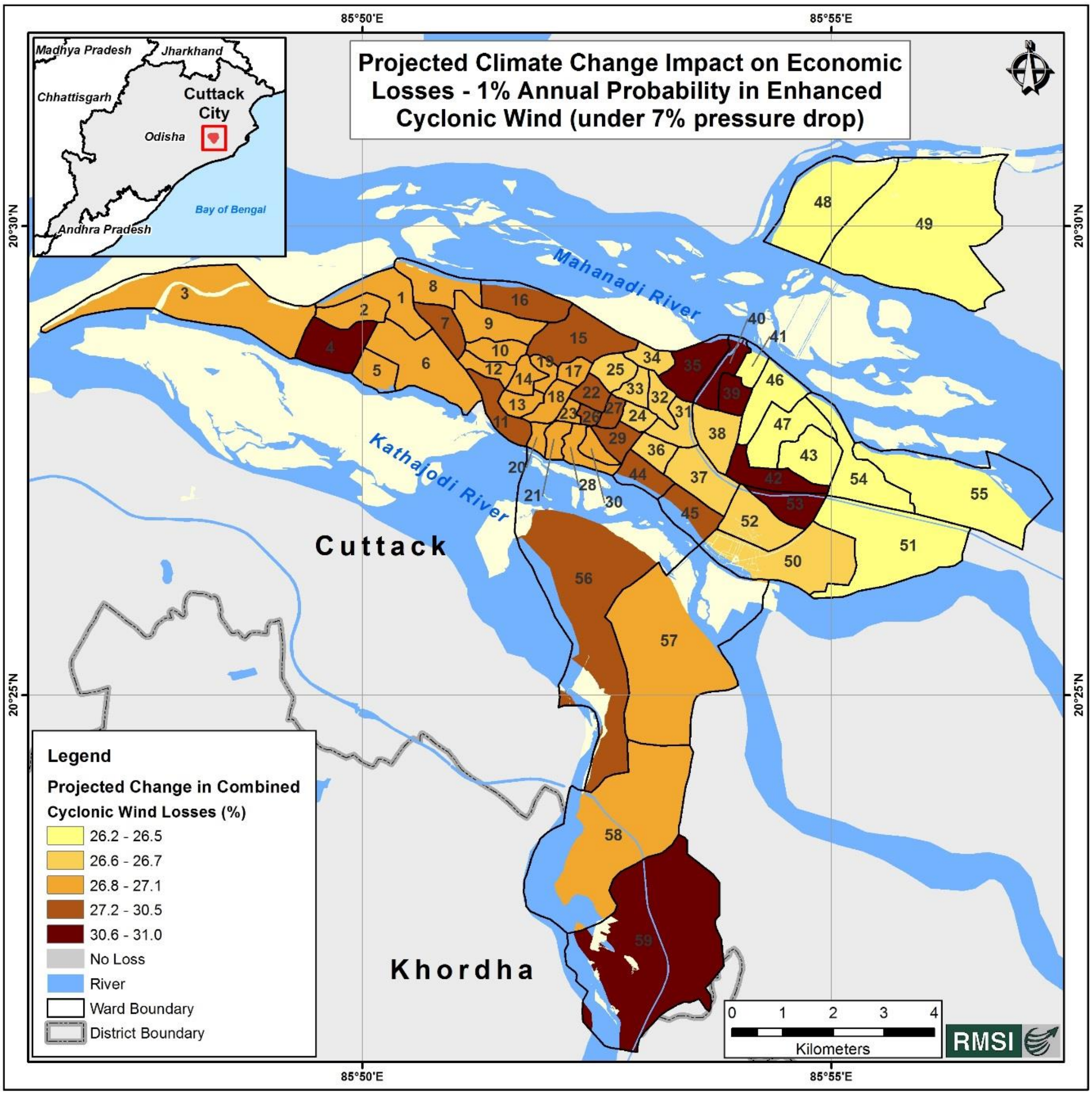

Figure 5-8: Ward wise estimated change in losses due to climate change impact (7%) on 1% annual probability cyclonic wind

Ward wise estimated increase in losses due to climate change impact (7% and 11%) on 4% and 2% annual probability cyclonic wind events are depicted in Figure 8-42 to Figure 8-45 under *Annexure-Cyclonic wind Assessment*.

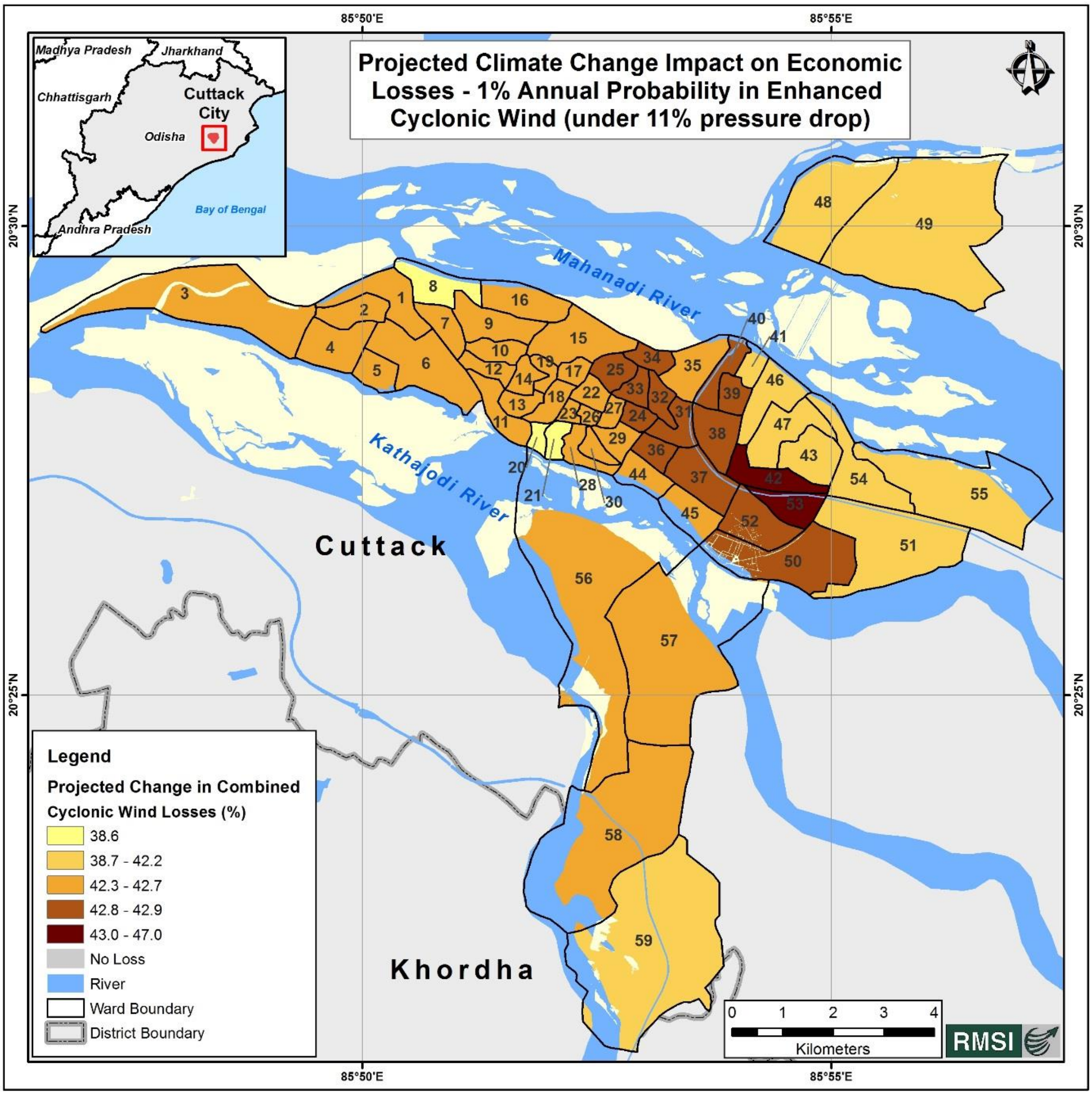

Figure 5-9: Ward wise estimated change in losses due to climate change impact (11%) on 1% annual probability cyclonic wind

5.1.2 FLOOD HAZARD

After finalizing the hazard data and generation of flood hazard maps for Cuttack city, hazard maps were used for the assessment of damage and risk associated with the flood hazard. Flood hazard associated loss assessment has been carried out based on the frequency and severity of various flood events at different return periods ranging from events that are more frequent to rare. For the analysis, the various datasets such as flood depths and extent, exposure, and vulnerability curves are used to analyze the damage and risk.

Before analyzing the losses, the various loss scenario terms used in the report have been re-defined for the convenience of the reader. The table also recaps corresponding rainfall volumes for Cuttack city for various flood events (Table 5-10).

Table 5-10: Recurrence intervals, probabilities of occurrences, and percentage chance of occurrences, and equivalent rainfall volume for Cuttack city

Sr. No.	Return period years	Probability of occurrence in a year	Percentage chance of occurrence in a year	Equivalent rainfall volume, mm
1	2	1 in 2 chances	50%	108
2	5	1 in 5 chances	20%	170
3	10	1 in 10 chances	10%	216
4	25	1 in 25 chances	4%	283
5	50	1 in 50 chances	2%	337
6	100	1 in 100 chances	1%	398

5.1.2.1 Estimated Potential Flood Hazard Losses for General Occupancy

The estimates of potential losses due to the flood hazard are summarized in Table 5-11 below, for general occupancy (residential, industrial, and commercial) classes. Six annual probabilities of occurrence (50%, 20%, 10%, 4%, 2% and 1%) are used for the potential loss estimations.

From Table 5-11, it is clear that PML from flood hazard are significant for residential and commercial occupancies as compared to the industrial losses. The losses in both the residential and commercial occupancies are consistently increasing from higher probability of occurrences to the lower probability of occurrences. The losses are expected to almost double from 2% probability to 1% probability. For 1% annual occurrence flood, the losses are estimated at INR 22.66 crores, INR 3.68 crores, and INR 0.11 crores for residential, commercial, and industrial occupancies respectively.

Table 5-12 presents distribution of ward-level potential losses to residential buildings for 15 most affected wards in Cuttack city. The table clearly shows that ward number 15 and 35 are most loss producing wards. The losses have been sorted based on high to low frequency of occurrences.

Similarly, Table 5-13 and Table 5-14 summarize the ward-level distribution of potential losses due to commercial and industrial buildings respectively.

Table 5-11: Potential maximum losses due to flood Hazard in Cuttack city

Probability of occurrence	Estimated potential losses to general occupancies (INR crores)		
	Residential	Commercial	Industrial
50%	7.60	0.47	0.00
20%	8.85	0.87	0.02
10%	9.97	1.13	0.04
4%	11.46	1.67	0.06
2%	12.05	1.82	0.08
1%	22.66	3.68	0.11

Table 5-12: Structural loss matrices corresponding to various annual flood probabilities for residential buildings in Cuttack city

Ward No.	Estimated potential losses for 15 most affected wards (INR crores)					
	50%	20%	10%	4%	2%	1%
15	4.15	4.60	4.75	4.91	4.99	5.20
35	1.15	1.24	1.34	1.45	1.55	1.83
24	0.34	0.46	0.62	0.72	0.73	1.10
9	0.22	0.25	0.29	0.36	0.37	0.66
57	0.21	0.26	0.30	0.40	0.45	0.52

Ward No.	Estimated potential losses for 15 most affected wards (INR crores)					
	50%	20%	10%	4%	2%	1%
39	0.19	0.20	0.21	0.22	0.22	0.33
20	0.16	0.16	0.17	0.17	0.17	0.30
33	0.13	0.23	0.33	0.40	0.41	0.91
41	0.12	0.13	0.14	0.16	0.17	0.26
30	0.10	0.12	0.13	0.14	0.15	0.46
12	0.09	0.11	0.14	0.16	0.18	0.26
11	0.09	0.11	0.12	0.14	0.15	0.27
7	0.09	0.10	0.11	0.11	0.11	0.37
29	0.08	0.11	0.12	0.14	0.14	0.29
8	0.07	0.10	0.12	0.23	0.24	0.36

Table 5-13: Structural loss matrices corresponding to various annual flood probabilities for commercial buildings in Cuttack city

Ward No.	Estimated potential losses for 15 most affected wards (INR crores)					
	50%	20%	10%	4%	2%	1%
57	0.21	0.26	0.30	0.40	0.45	0.52
24	0.06	0.08	0.09	0.10	0.10	0.12
29	0.06	0.14	0.17	0.20	0.20	0.37
46	0.05	0.07	0.08	0.09	0.10	0.24
18	0.04	0.04	0.04	0.04	0.04	0.08
21	0.02	0.02	0.04	0.05	0.05	0.10
11	0.02	0.02	0.02	0.03	0.03	0.03
20	0.01	0.01	0.01	0.01	0.01	0.01
41	0.00	0.00	0.00	0.01	0.01	0.01
30	0.00	0.00	0.00	0.00	0.00	0.02
25	0.00	0.00	0.00	0.00	0.00	0.03
40	0.00	0.00	0.00	0.00	0.00	0.02
35	0.00	0.00	0.00	0.00	0.00	0.02
31	0.00	0.00	0.03	0.03	0.04	0.15
47	-	0.17	0.19	0.42	0.45	0.51

Table 5-14: Structural loss matrices corresponding to various annual flood probabilities for industrial buildings in Cuttack city

Ward No.	Estimated potential losses for 15 most affected wards in Cuttack city (INR crores)					
	50%	20%	10%	4%	2%	1%
54				-	0.01	0.03
55		0.02	0.04	0.06	0.07	0.08

For better understanding of distribution of estimated potential losses due to various occupancy classes, spatial maps have been generated for these. Figure 5-10, Figure 5-11, and Figure 5-12 show the ward-level spatial distribution of estimated potential losses to these occupancy classes for flood with 1% annual probability of occurrence.

Figure 5-10 clearly shows the high residential building losses in the central part of Cuttack city in ward numbers 15, 35, 9, 17, 22, 24, 27, and 33. Map also shows significant losses in ward 51 in the southern part of the city.

Figure 5-11 shows the high commercial building losses in the southern part of Cuttack city in ward numbers 57, 47, 43, 46, 29, and 44. The map does not show any losses in other wards because of the absence of commercial buildings in these wards.

Ward-level distribution of estimated potential losses for industrial buildings due to 1% annual probability flood is shown in Figure 5-12. The map shows that there is almost no loss in any ward except in ward numbers 54 and 55.

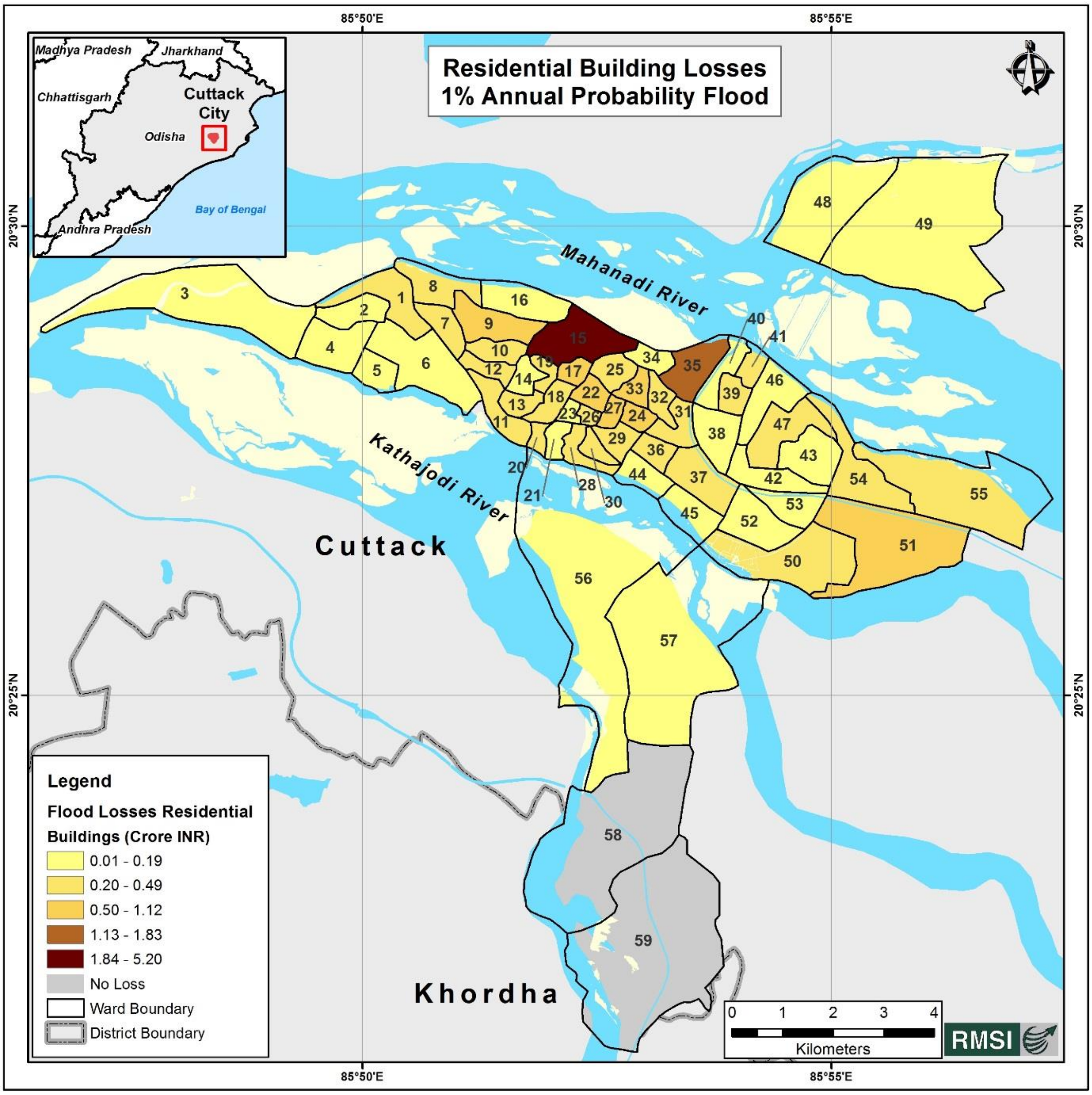

Figure 5-10: Ward-level distribution of estimated potential losses for residential occupancy due to 1% annual probability flood

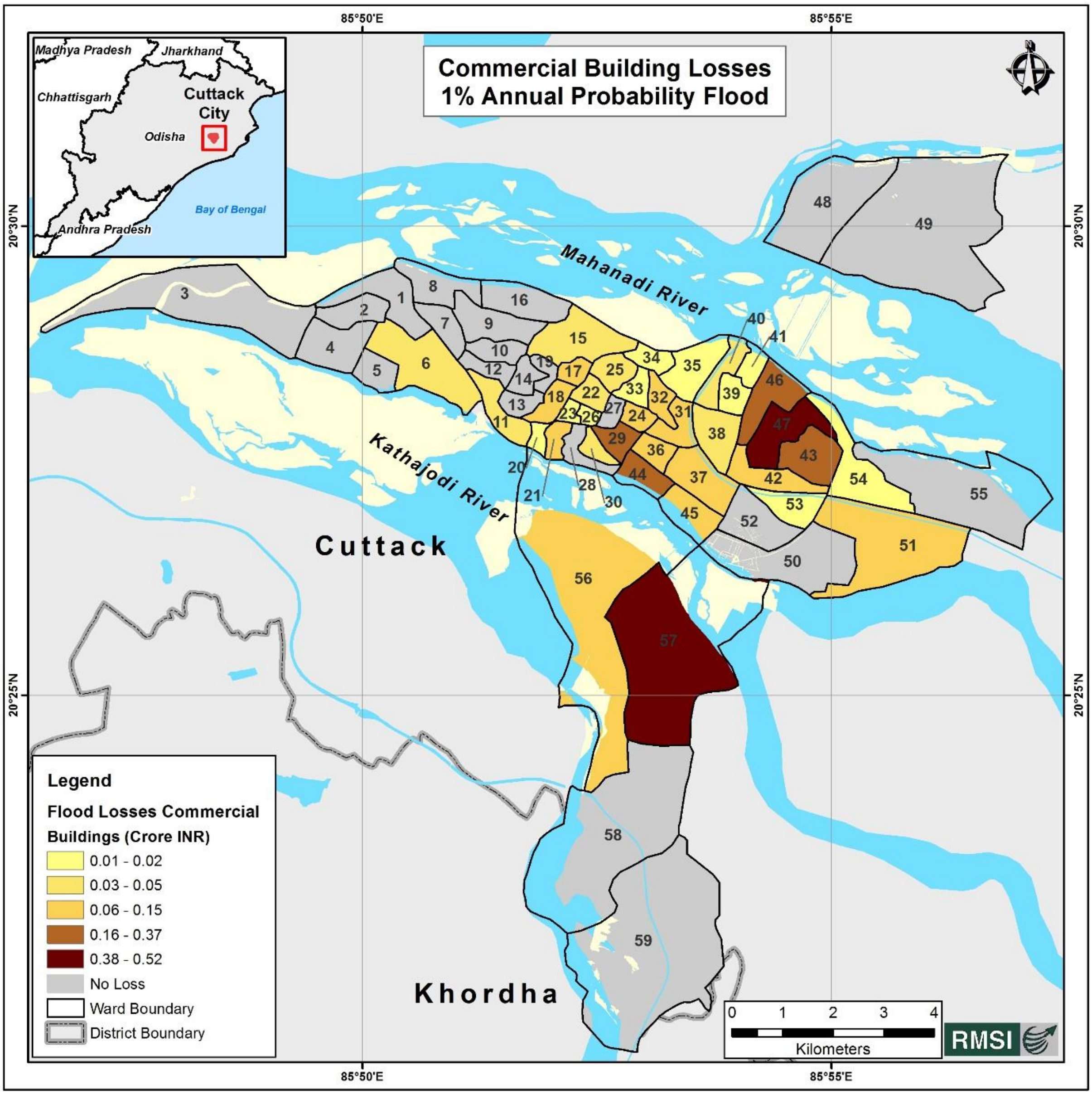

Figure 5-11: Ward-level distribution of estimated potential losses for commercial occupancy due to 1% annual probability flood

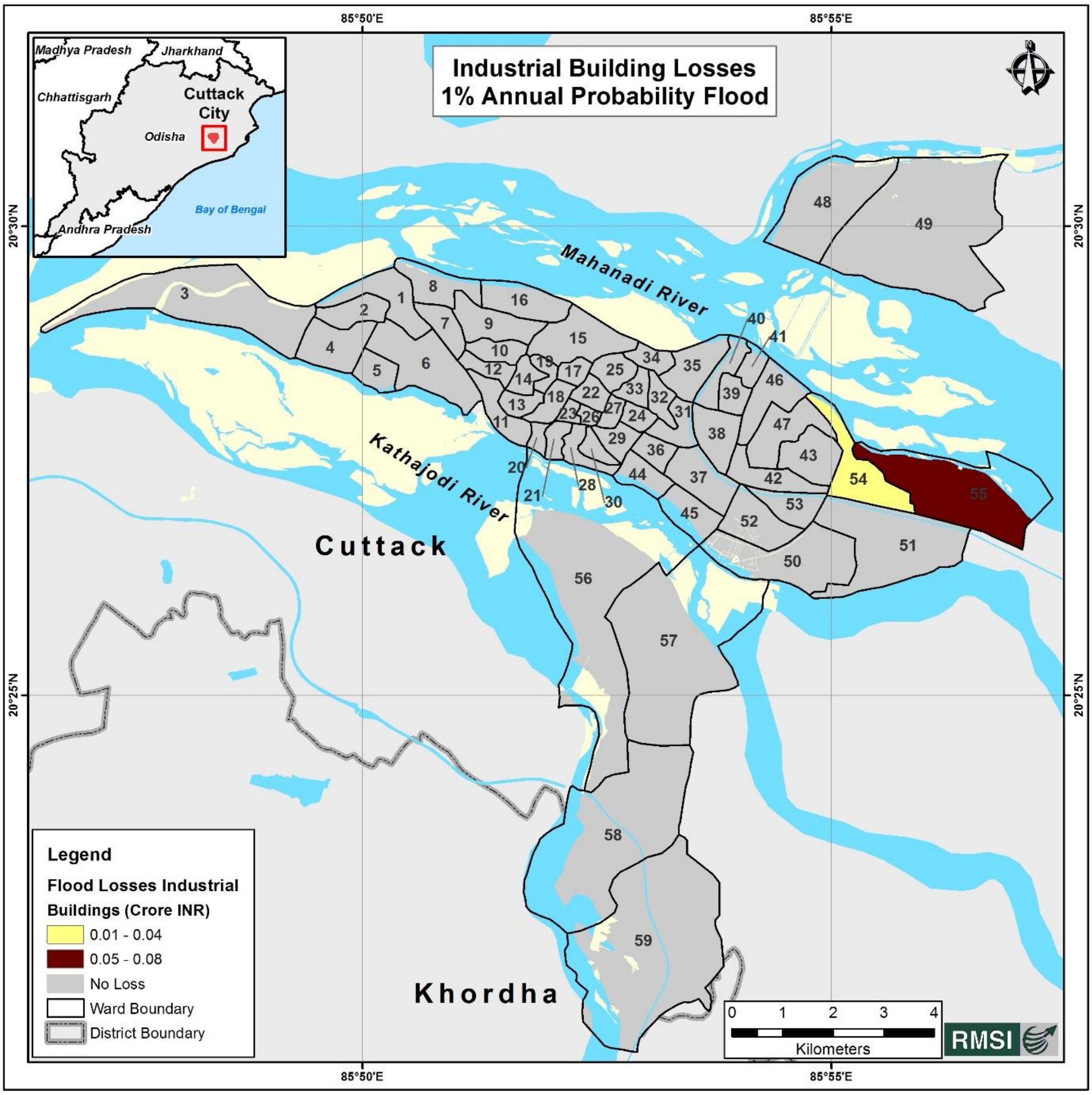

Figure 5-12: Ward-level distribution of estimated potential losses for industrial occupancy due to 1% annual probability flood

5.1.2.2 Estimated Potential Flood Hazard Losses Due to Affected Essential Facilities and Utilities

Similar to the estimated potential losses to general occupancies, the losses to various utilities and essential facilities have also been estimated. These sectors include utility classes (electricity, communication, portable water, and waste water) and other essential facilities (schools, hospitals, fire stations, police stations, and places of worships) etc.

Table 5-15 summarizes the estimated potential losses to these exposure classes due to the various annual probabilities of occurrences (50%, 20%, 10%, 4%, 2% and 1%). It is inferred from the table that most of the losses are in affected schools and hospitals as compared to other losses.

Table 5-15: Estimated losses corresponding to various annual flood probabilities for essential facilities and utility classes in Cuttack city

Essential Facility/ Utility Classes	Estimated potential losses in Cuttack city (INR crores)					
	50%	20%	10%	4%	2%	1%
Electricity	0.00	0.01	0.01	0.01	0.02	0.06
Hospital	0.09	0.16	0.24	0.34	0.41	1.25
Religious Places	0.01	0.03	0.04	0.06	0.07	0.21
School	0.20	0.36	0.55	0.79	0.95	2.88
Fire Station	0.03	0.03	0.03	0.03	0.03	0.05
Police Station	0.01	0.02	0.02	0.02	0.02	0.04
Communication	0.00	0.00	0.00	0.00	0.00	0.00
Potable Water	0.00	0.00	0.00	0.01	0.01	0.15
Waste Water	0.00	0.01	0.01	0.01	0.02	0.18

5.1.2.3 Estimated Potential Flood Hazard Losses Due to Affected Transportation Structures

The losses and damages to transportation structures due to flooding contribute significantly in the estimated combined potential losses. Four-transportation structure types namely, roads, railway lines, bridges, and railway stations have been considered for loss assessment. Table 5-16 summarizes the estimated potential flood losses to these exposure classes due to various annual probabilities of occurrences (50%, 20%, 10%, 4%, 2% and 1%). It can be seen from the table that estimated potential losses are dominated by road losses, followed by railway line losses. The losses to bridges and railway stations are considerably insignificant. Road losses are consistently increasing from higher probabilities of occurrences to the lower probabilities of occurrences. The expected losses increase almost 10 times from a frequent flood event (50% occurrence) to a rare flood event (1%).

Table 5-16: Estimated losses corresponding to various annual flood probabilities for different transportation structures classes

Transportation Structures	Estimated potential losses in Cuttack city (INR crores)					
	50%	20%	10%	4%	2%	1%
Bridge	0.04	0.17	0.26	0.44	0.56	0.67
Railway Line	0.26	0.41	0.51	0.63	0.70	1.24
Railway Station	0.00	0.01	0.01	0.01	0.01	0.07
Road	1.48	3.07	5.36	6.95	8.39	15.18

5.1.2.4 Estimated Potential Damages to Essential Facilities and Transportation Structures

Table 5-17 summarizes the estimated potential damages to essential facilities and transportation structures due to various flood event occurrence scenarios. The damage is predominantly to affected hospitals, schools, and religious places. Even in the case of more frequent events, with 50% chance of occurrence, there is massive damage to these three exposure classes. The estimated damage is 3-4 times in the case of events with lower chance of occurrences (1% or 2% annual probability floods).

Table 5-17: Estimated damage corresponding to various annual flood probabilities for different essential facilities and transportation structures classes

Essential Facilities/ Transportation Structures	Estimated potential damages for various flood event scenarios for Cuttack city (Nos.)					
	50%	20%	10%	4%	2%	1%
Hospital	40	53	59	72	75	154
Religious Places	90	117	130	159	166	339
School	53	68	76	93	97	199
Fire Station	1	1	1	1	1	1
Police Station	1	1	1	1	1	2
Railway Station	0	1	1	1	1	1
Bridges	2	5	5	5	5	7

Similar to damages estimated to various transportation structures and utilities, potential affected road lengths have also been estimated for various road types and summarized in Table 5-18. The table clearly indicates that link roads and major roads are majorly affected due to regular flooding.

Table 5-18: Estimated affected roads corresponding to various annual flood probabilities for different transportation structures classes

Affected Transportation Structures	Estimated potential damages for various flood event scenarios for Cuttack city (km.)					
	50%	20%	10%	4%	2%	1%
Link Roads	32.2	38.4	43.6	49.4	50.6	93.5
Major Roads	5.5	8.3	9.2	10.6	11.7	17.3
Minor Roads	0.3	0.4	0.4	0.4	0.4	0.6
National Highways	1.8	1.9	1.9	2.1	2.1	2.5
State Highways	0	0	0	0.1	0.1	1

5.1.2.5 Estimated Potential Affected Population and Households Due to Flood Hazard

Flood impacts the city not only due to damages and due to economic losses caused to buildings, essential facilities, and transportation structures, but also affects the population and households living in the flood-inundated areas. The affected population and households are the function of the residential units in inundation areas.

Table 5-19 provides a statistical summary of the affected households and population, total population, and the percentage of affected population of total population of the Cuttack city. It can be seen from table that around 37,499 people (6%) and 3,564 households are likely to get affected due to a very frequently occurring flood event (50% chance of occurrence in any year). However, affected population increases almost three times for floods with a rare chance of occurrence. Almost 17% population is expected to get affected in the case of a rare event such as 1% chance of occurrence.

Table 5-19: Total, affected, and percentage affected population corresponding to various annual flood probabilities in Cuttack city

Population	Total affected population in Cuttack city					
	50%	20%	10%	4%	2%	1%
Affected Population	37,499	45,811	48,456	55,849	57,458	1,14,056
Total Population	6,59,121	6,591,21	6,59,121	6,59,121	6,59,121	6,59,121
Percentage Affected	6%	7%	7%	8%	9%	17%
Affected Households	7,564	9,241	9,774	11,273	11,597	23,011

For understanding the social flood vulnerability of Cuttack city, ward-level total affected population has been estimated corresponding to various annual flood occurrence probabilities in Cuttack city. Table 5-20 presents a list of 15 most flood affected wards in Cuttack city based on affected population. The list is sorted based on the affected population for a frequent event to rare flood events. The table provides a comprehensive summary of the wards, which are more or less affected due to each flood event. The list clearly shows that the population residing in ward numbers 15 and 35 are most prone to flood losses.

Table 5-20: Ward-level total affected populations corresponding to various annual flood probabilities in Cuttack city

Ward No.	Total affected population for 15 most affected wards in Cuttack city					
	50%	20%	10%	4%	2%	1%
15	8,854	8,894	8,904	8,904	8,904	10,110
35	5,170	5,627	5,804	5,840	5,840	6,305
24	2,542	3,802	3,899	3,899	3,899	5,571
9	1,669	1,749	1,829	2,283	2,283	3,550
12	1,385	1,439	1,705	1,758	1,758	1,918
33	1,302	2,661	2,661	2,661	2,661	4,740
10	1,252	1,799	1,799	2,073	2,112	2,660
27	1,239	2,955	3,051	3,051	3,051	5,720
30	1,083	1,203	1,203	1,444	1,504	2,995
39	1,059	1,059	1,059	1,059	1,059	1,428
29	983	1,015	1,040	1,064	1,089	2,425
41	952	952	952	1,026	1,026	1,026
11	868	1,019	1,049	1,049	1,049	1,836
8	855	898	941	2,027	2,048	2,176
20	854	854	854	854	854	1601

Moreover, there are many wards, which are vulnerable to only extreme or rare flood events. They are at no risk due to the regular occurring flood events. However, if we look at the extreme flood events, populations in a higher number of wards get affected. Figure 5-13 depicts the comparative distribution of ward wise affected population for the 30 most affected wards due to a flood event with 1% annual probability of occurrence.

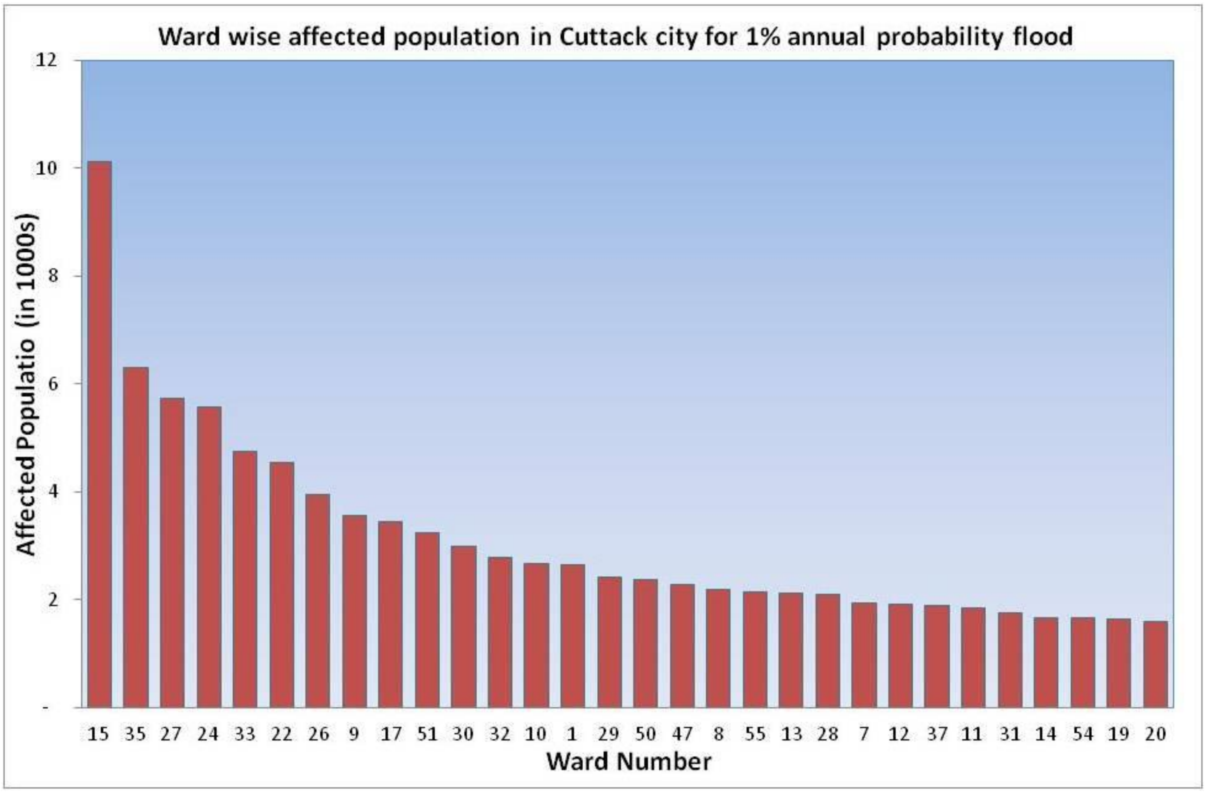

Figure 5-13: A comparative ward-level distribution of affected population for a 1% annual probability flood event

5.1.2.6 Combined Losses, AAL and LEC

Once the potential losses to various exposure classes in the city were arrived at, a combined loss matrix was also prepared by combining all the expected losses in a ward. Table 5-21 provides a gist of estimated potential losses spreading across the various exposure classes corresponding to various annual flood probabilities of occurrences. It provides a comparative view across the sector-specific losses and can be useful for administrators and the city authorities for decision-making regarding fund allocation for long-term and short-term strategies.

Figure 5-14 shows the ward-level spatial distribution of combined losses for a probable flood event with 1% chances of occurrence annually. Similarly, Figure 8-47 and Figure 5-14 in *Annexure - Flood Risk Assessment* show the combined losses corresponding to 2% and 4% annual probability flood events.

Table 5-21: Combined losses due to flood with various annual probabilities in Cuttack city

Exposure Class	Combined losses for various flood event scenarios for Cuttack city (INR crores)					
	50%	20%	10%	4%	2%	1%
Residential	7.60	8.85	9.97	11.46	12.05	22.66
Commercial	0.47	0.87	1.13	1.67	1.82	3.68
Industrial	0.00	0.02	0.04	0.06	0.08	0.11
Essential Facilities	0.34	0.59	0.88	1.23	1.48	4.42
Utilities	0.01	0.01	0.02	0.03	0.05	0.40
Transportation Infrastructures	1.78	3.66	6.14	8.03	9.67	17.16

Exposure Class	Combined losses for various flood event scenarios for Cuttack city (INR crores)					
	50%	20%	10%	4%	2%	1%
Combined Losses	10.20	14.00	18.18	22.47	25.14	48.43

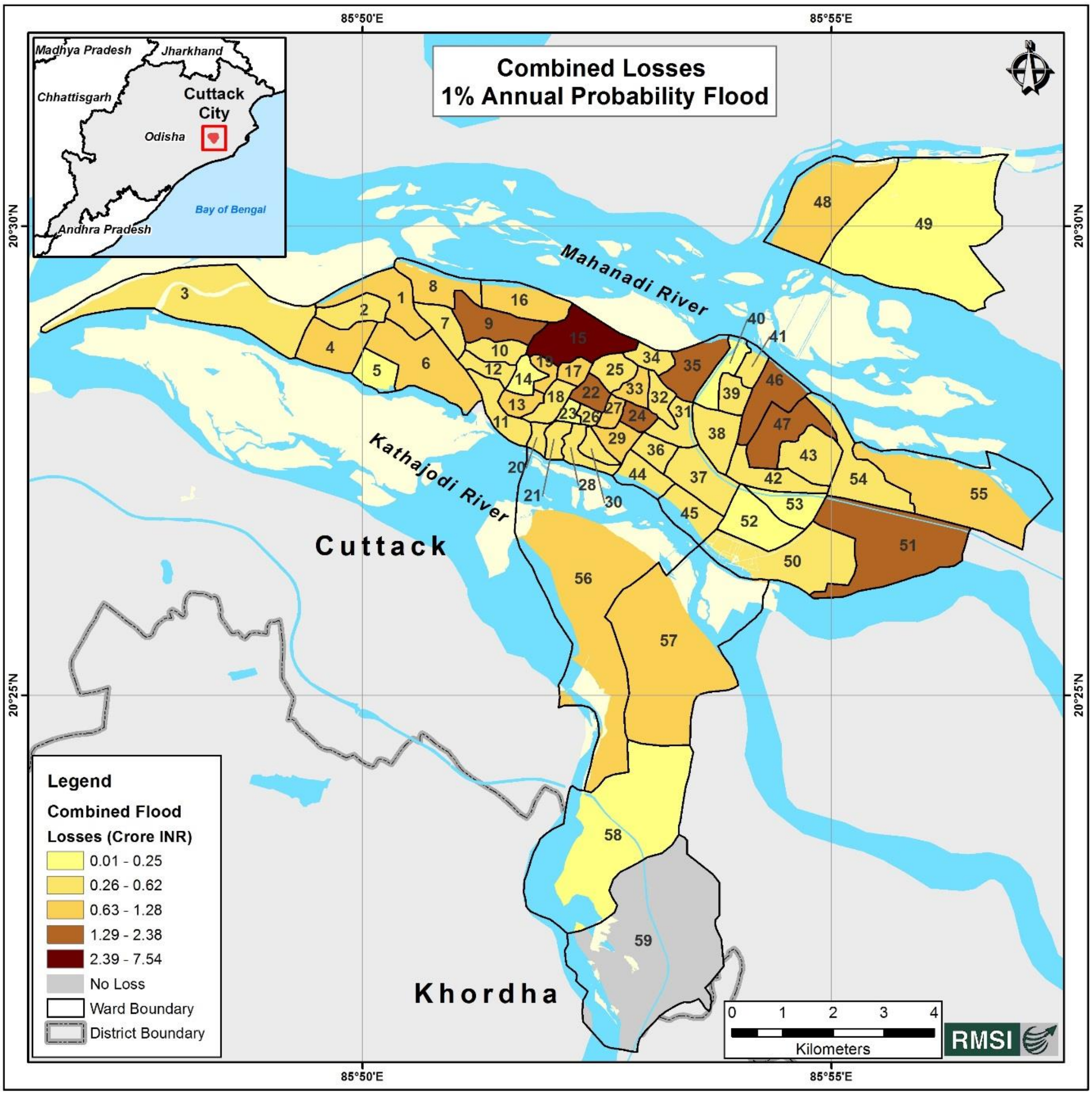

Figure 5-14: Ward-level distribution of estimated combined potential losses due to for 1% annual probability flood

After estimating the potential losses due to a number of probable flood events ranging from 50% annual probability of occurrence to 1% annual probability of occurrence, it becomes essential to know the AAL that can occur during any year. AAL is the mean or average of the loss distribution curve that is averaged over many years.

Figure 5-15 shows the map of spatial distribution of ward wise average annualized losses for Cuttack city. The AAL map shows that ward numbers 15 and 35 are most vulnerable as per the combined losses followed by ward number 9, 24, 46, 47, and 57. Combined potential losses are dominated mainly by residential and road losses.

Table 5-22 provides a comparative distribution of various components contributing to the combined AAL and AAL as a percentage of the total corresponding value of exposure.

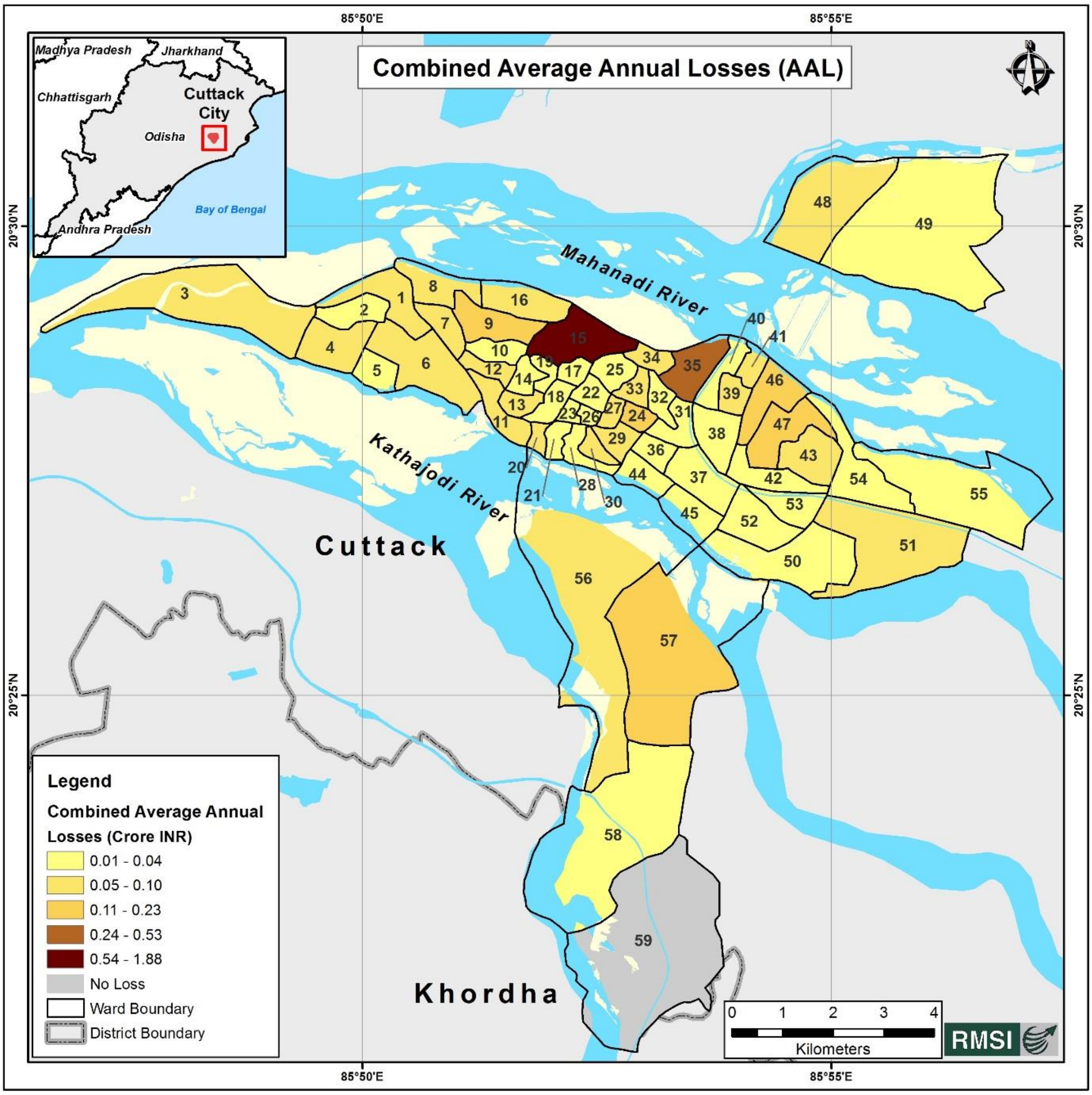

Figure 5-15: Spatial distribution of ward wise average annualized losses for Cuttack city

Table 5-22: AALs corresponding to different exposure classes

Exposure Classes	AALs in INR crores	AAL as % of Total Exposure Value
Residential	3.50	0.049
Commercial	0.32	0.014
Industrial	0.01	0.000
Essential Facilities	0.26	0.021
Utilities	0.01	0.001
Transportation Infrastructures	1.06	0.027
Combined	5.15	0.030

LEC curves for various exposure classes, showing a relationship between the estimated potential losses and corresponding probabilities, have been plotted in Figure 5-16.

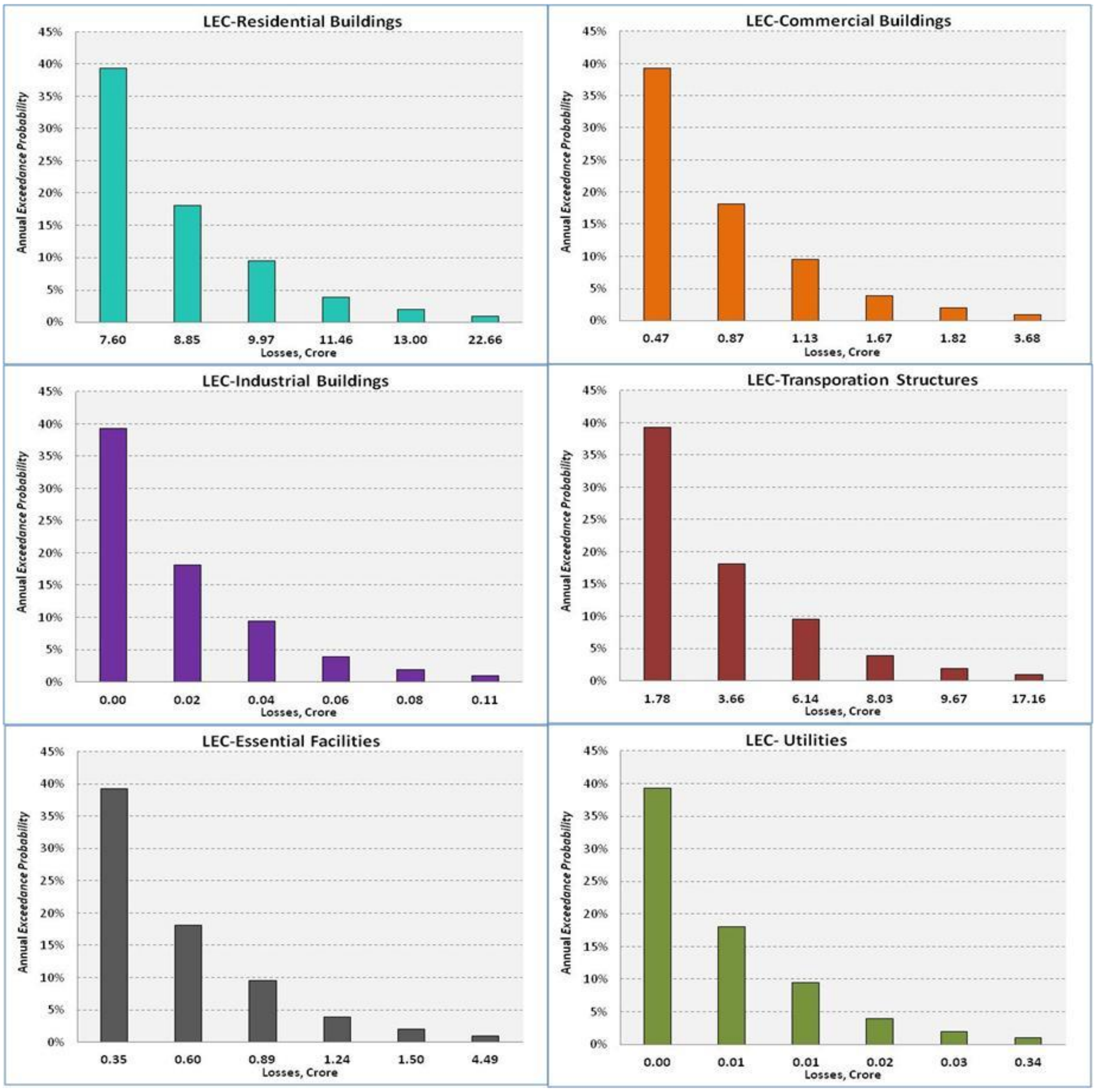

Figure 5-16: LEC for various exposure classes

5.1.2.7 Impact of Climate Change Projections on Flood Losses

In order to understand the possible impact of projected climate change scenarios on flood losses, flood loss mapping was carried out. The analysis of climate change projections shows that the rainfall intensity will increase by 1.65%, 6.25%, and 9.65% (for the monsoon period) from the current climatic conditions. From these three climatic change scenarios, only scenarios 1 (6.25% change) and scenario 2 (9.65% change) show some significant changes in future climatic conditions. The potential flood losses have been estimated on considering impact of these climate change scenarios on flood hazard.

Table 5-23 shows changes in flood losses due to climate change impact for 1%, 2%, and 4% annual occurrence floods for scenario 1 (6.25% change) and scenario 2 (9.65% change) respectively.

The analysis shows that flood losses are expected to double under the impact of climate change for high occurrence flood events. However, for extreme events, such as 1% annual occurrence floods, the losses are expected to increase between 10% to 16%. Figure 5-17 shows the ward-level spatial distribution of change in flood losses for Cuttack city.

Table 5-23: Impact of climate change on flood losses for key flood events

Climate Change Scenarios	Changes in rainfall intensity	
	Scenario 1 (6.25%)	Scenario 2 (9.65%)
4% Annual occurrence flood	110%	119%
2% Annual occurrence flood	106%	117%
1% Annual occurrence flood	10%	16%

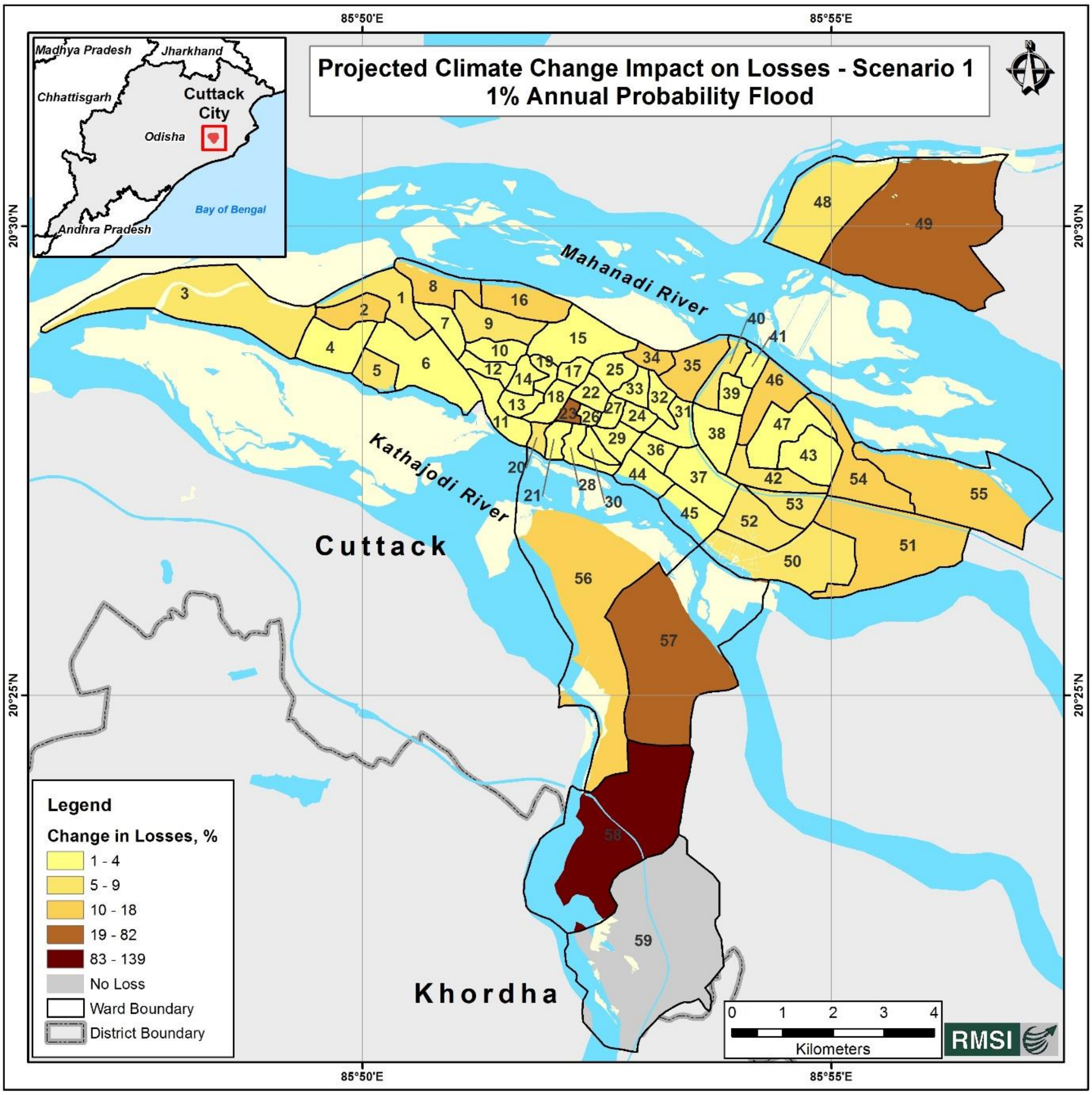

Figure 5-17: Projected climate change impact on ward-level flood losses in Cuttack city for 1% annual probability flood

5.1.3 EARTHQUAKE

As per the Seismic Zoning Map of India (IS: 1893, 2002, 2014), Cuttack city is located in seismic zone-III. Cuttack and its surrounding regions lie in a Stable Continental Region (SCR) that is not seismically very active. However, minor to moderate earthquakes (not of damaging scale) have occurred in the past at different localities. In the recent past, the maximum magnitudes reported are around 4.5 to 5.3 on the Richter's scale and the maximum-recorded intensity in Cuttack city so far is about VI on the MSK Intensity scale. In spite of the moderate, non-damaging earthquakes observed so far in and near Cuttack, it cannot be confidently said that higher intensity earthquakes are unlikely in the future. Recently, on May 21, 2014, an earthquake of magnitude 6 occurred in the Bay of Bengal, which was severely felt in different parts of Cuttack city. However, there was no significant damage reported in the city. A comprehensive modeling approach was adopted for earthquake hazard and risk assessment (please refer to the earthquake hazard section in the Component 1, 2, and 3 report). The Table 5-24 below provides estimates of PML for general occupancy (residential, industrial, and commercial) classes due to Earthquake hazard scenario of 475-years return period. Accordingly, losses are presented at ward-level for this scenario-event (Figure 5-18, Figure 5-19 and Figure 5-20 for residential, commercial, and industrial structures, respectively). The table shows that probable maximum losses are to the order of INR 785 crores (8% of total exposure value) for residential buildings, INR 513 crores (17% of total exposure value) for commercial buildings and INR 571 crores (24% of total exposure value) for industrial buildings.

Table 5-24: PML for the Earthquake Hazard in Cuttack city

Return Period Years	Losses (INR crores)		
	Residential	Commercial	Industrial
475	785	513	571

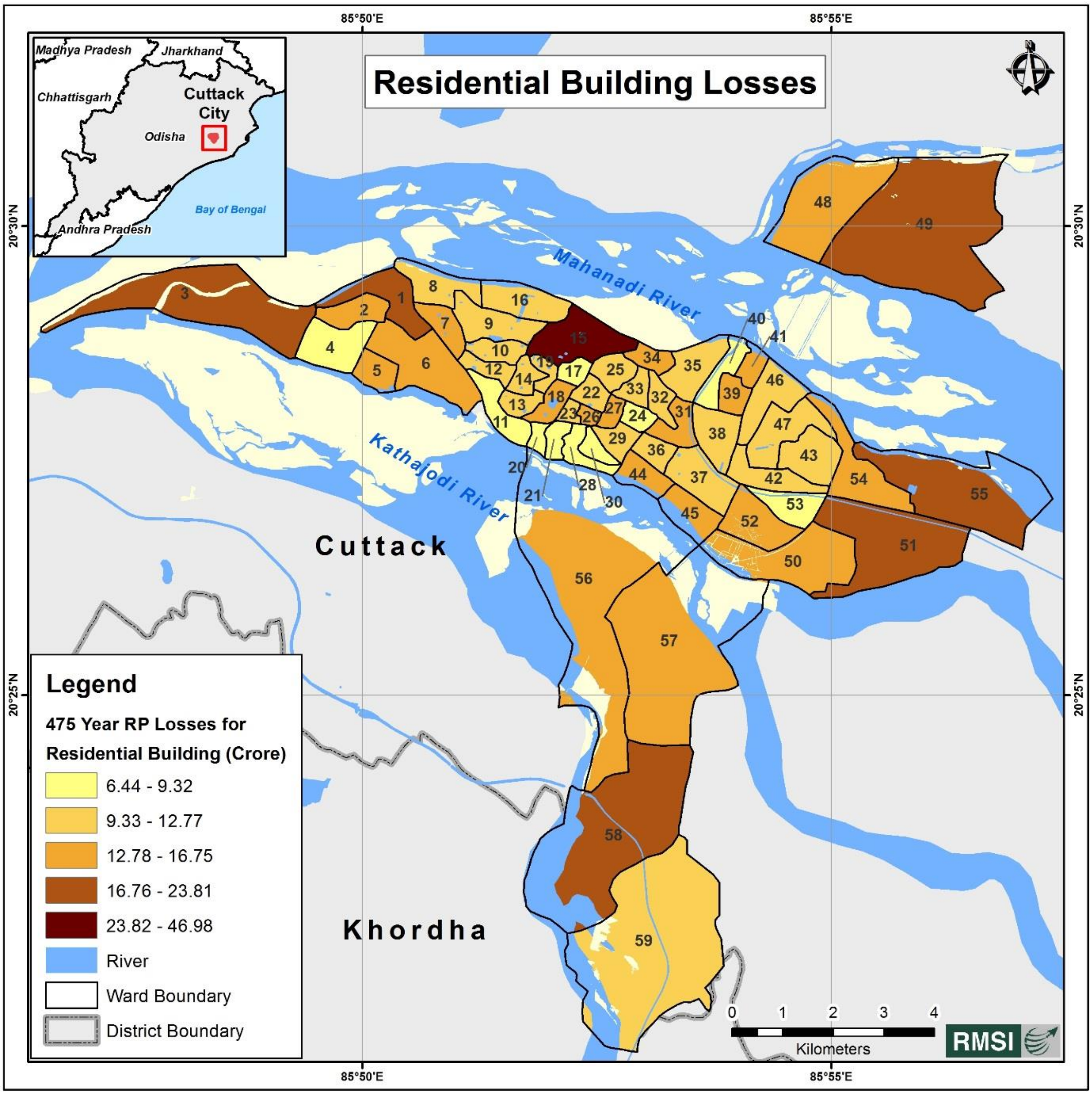

Figure 5-18: Distribution of Structural Losses (PML) corresponding to 475-years return period hazard scenario event for residential buildings in Cuttack city

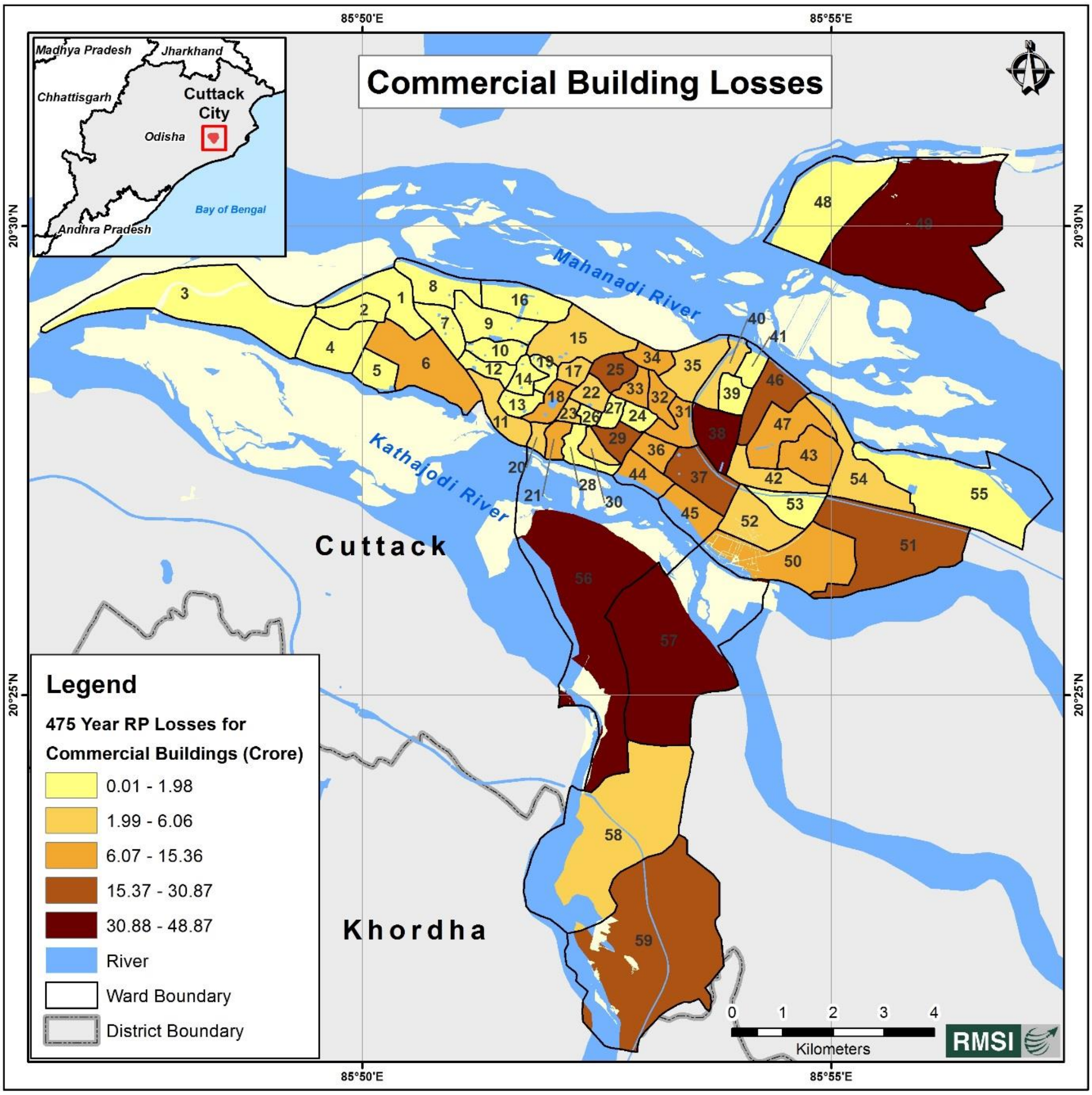

Figure 5-19: Distribution of Structural Losses (PML) corresponding to 475-years return period hazard scenario event for commercial buildings in Cuttack city

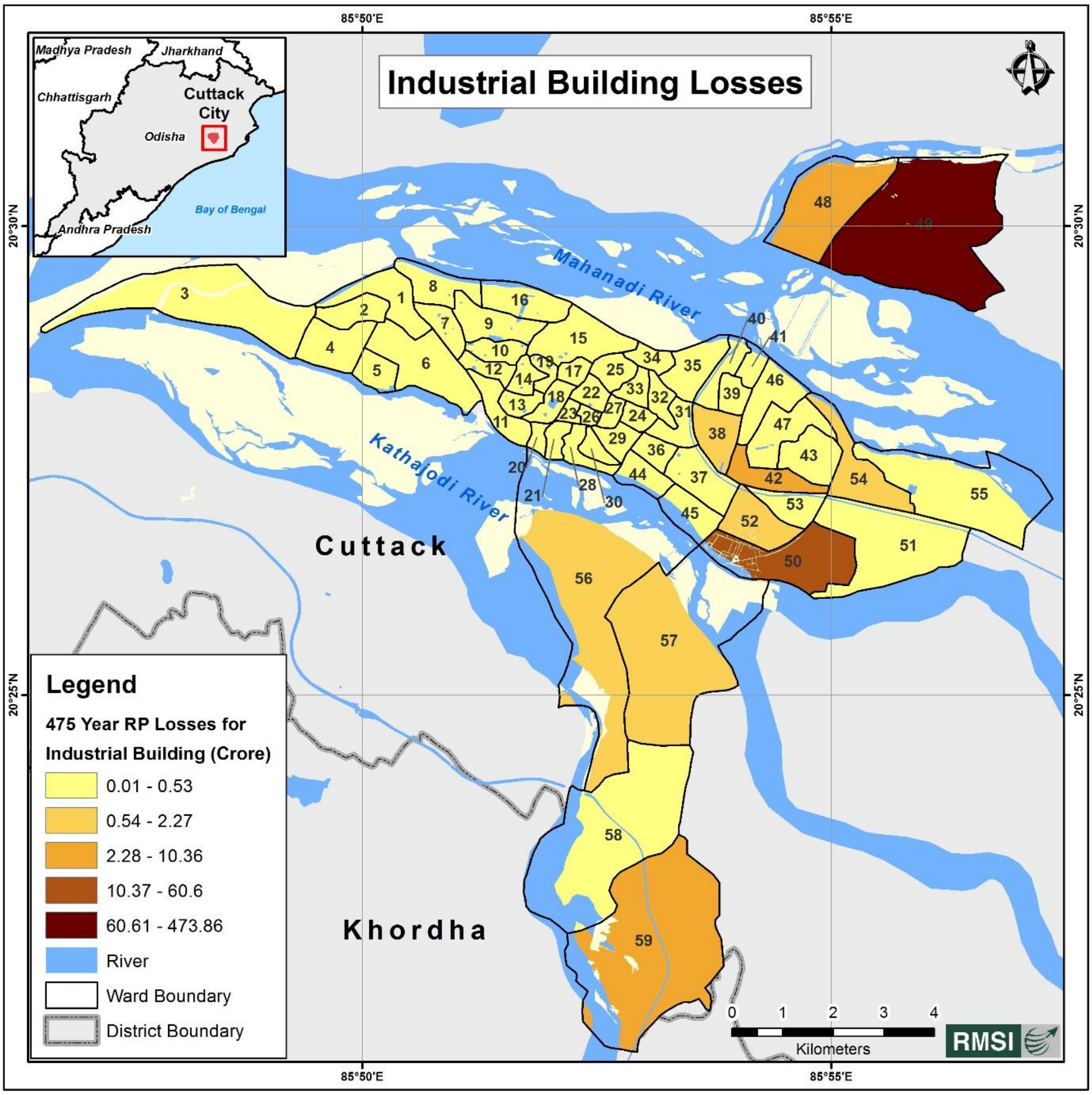

Figure 5-20: Distribution of Structural Losses (PML) corresponding to 475-years return period earthquake hazard scenario event for industrial buildings in Cuttack city

5.1.3.1 Projections of Losses to Various Sectors

Table 5-25 provides estimates of projected losses to various sectors for the earthquake hazard for ground motions having 10 percent probability of being exceeded in 50 years. These sectors include transport (roads, railway lines), utility networks (electric lines, water lines, sewerage lines), and other facilities (schools, hospitals, places of worship) etc. From this table, it can be seen that maximum losses are expected in the education sector, which is to the order of INR 74 crores.

Table 5-25: Estimation of projected losses to various sectors for the earthquake hazard for ground motions 10% probability of exceedance in 50 years

Facility/Sectors	No. of facilities/ length	Losses corresponding to 10% probability of exceedance
		INR crores
Facilities		
Hospitals	672	32
Schools/Colleges	870	74
Places of Worship	1,480	5
Administrative Headquarters	1	-
Fire stations	3	-
Police Stations	17	-
Transport		
Road, km (National Highway)	41	4.47
Road, km (State Highway)	4	0.50
Road, km (Major Road)	80	5.98
Road, km (Minor Road)	3	0.09
Road, km (Link Road)	587	23.8
Railway Lines, km	42	No Loss
Bridges	26	73
Railway Station	4	4.35
Utility Networks		
Water Lines, km	383	1.25
Sewerage Line, km	445	1.34
Electricity System	-	18.15

5.2 Hazard Risk Hotspots in Cuttack

Based on the intensity of hazard, each ward has been ranked from 1 to 3 categories where rank 1 indicates low, rank 2 indicates medium, and rank 3 indicates high hazard intensity.

Table **5-26** represents composite hazard index across various wards. Ward-level composite hazard index information will help in city planning, including deciding upon new investments.

Based on risk to various hazards, ward level Composite Risk for the city was calculated at ward level. The steps followed for developing the Composite Risk were:

- Hazard wise risk (economic losses) calculated at ward level for cyclonic wind, flood, and earthquake
- Ranking of wards has been done based on risk values
- Calculating mean value and standard deviation (after eliminating the extreme values)
- Values below (mean minus standard deviation) are consider low, values above (mean plus standard deviation) are high and values that fall between are categorized as medium
- The ranks of all the hazards were added and normalized to develop the Composite High Risk wards and were plotted in GIS at ward level

Table 5-26: Composite hazard index

Ward No.	Earthquake	Flood	Cyclone	Ward No.	Earthquake	Flood	Cyclone
1	2	2	2	31	3	2	2
2	2	2	1	32	2	1	2
3	2	2	1	33	2	3	2
4	2	3	1	34	2	2	2
5	2	1	2	35	2	3	2
6	2	2	2	36	2	2	2
7	2	2	2	37	3	2	2
8	2	3	1	38	3	2	2
9	2	3	2	39	2	2	2
10	2	2	2	40	2	2	2
11	2	2	2	41	2	2	2
12	2	2	2	42	2	2	3
13	2	2	2	43	2	2	2
14	2	2	2	44	2	1	2
15	3	3	2	45	2	1	2
16	2	3	2	46	3	3	3
17	2	1	2	47	2	3	2
18	2	2	2	48	2	3	2
19	2	1	2	49	3	1	3
20	2	2	2	50	3	1	3
21	2	2	2	51	3	2	2
22	2	2	2	52	2	1	2
23	2	1	2	53	1	1	1
24	1	3	1	54	2	2	2
25	2	2	2	55	2	2	2
26	2	2	2	56	3	2	3
27	2	2	2	57	3	3	3
28	2	2	2	58	3	1	2
29	2	2	2	59	3	1	3
30	2	2	2				

The “Composite High Risk hotspots analysis” categorizes the city into high, medium, and low vulnerability areas based on the cumulative score of all the hazards considered for the analysis. Wards with high risk need priority interventions. A correlation between the location of slum pockets and the risk zones was performed in GIS and it was found that 40% of the slum pockets are in the high-risk zone. The low risk wards have 20% slum pockets while 40% of slum pockets are in medium risk zone. Figure 5-21 represents ward level composite risk wards. About 30% of the city population are living in composite high risk wards.

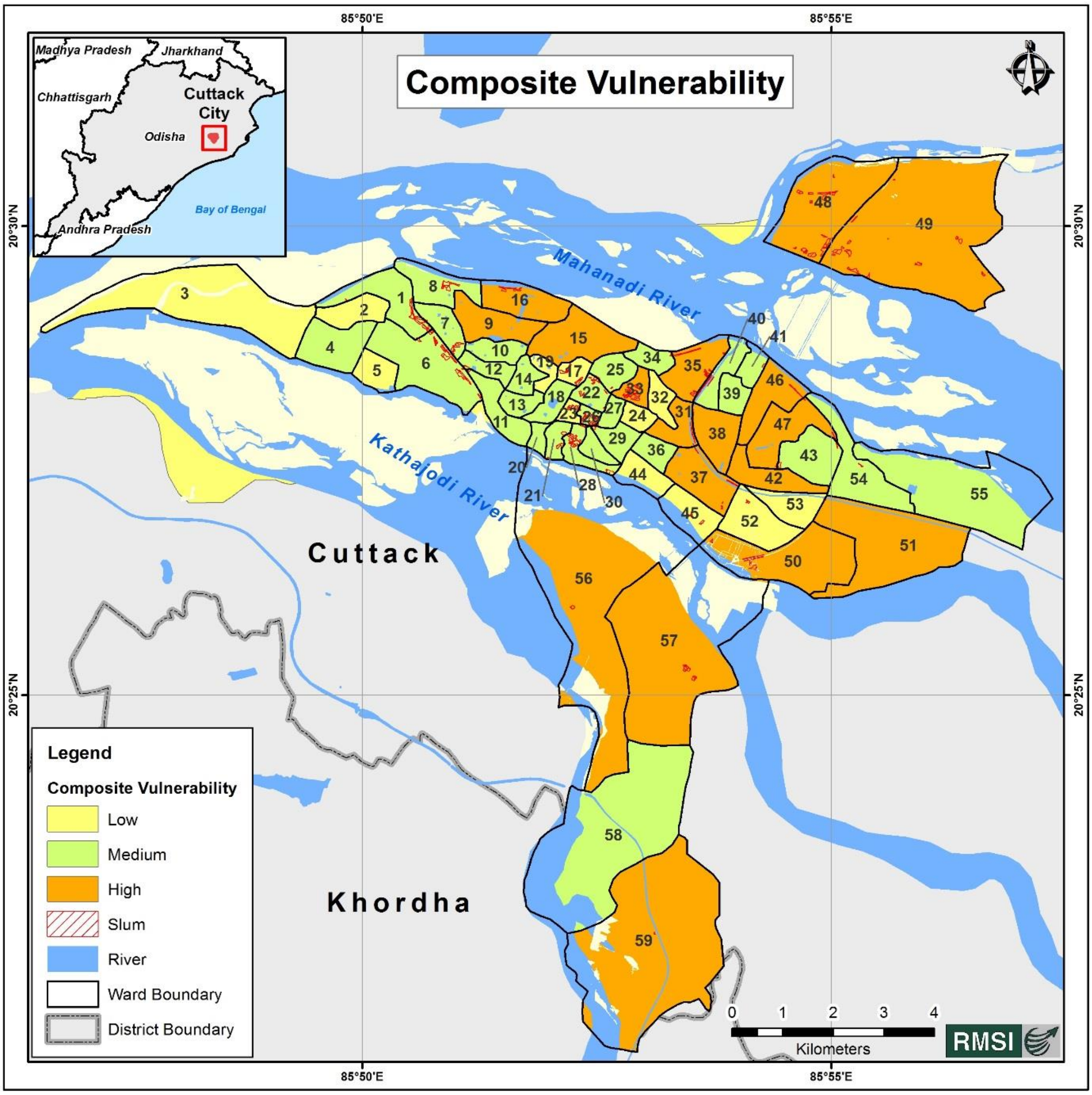

Figure 5-21: Ward level composite risk zones

5.3 Estimation of Affected Population and Expected Casualties

Earthquake's most damaging impacts are in terms of structural losses and number of casualties (serious injuries including fatalities). Majority of the fatalities and injuries are caused due to structural failure. As a part of the study, while estimating the probabilistic losses for ground motions 10% probability of exceedance in 50 years (475 year return-period) earthquake scenario event and its associated economic impacts, the affected population and casualties (serious injuries including fatalities) were also estimated.

Table 2-7 provides the estimates of earthquake-affected population and estimates of injuries including fatalities in Cuttack city. However, the injuries and casualties due to earthquake hazard is also a function of the time of occurrence and hence two typical scenarios (daytime 2:00 PM and nighttime 2:00 AM). If we consider the floating population also (daily commuting population) the numbers can be significantly higher. In the day-time scenario, the estimated casualties are between 1,681 – 1,845 people and the people likely to be affected are about 55,737. In the night time-scenario, the estimated casualties are between 4,203 – 4,613 people and the people likely to be affected are about 167,100.

Table 5-27: Estimated numbers of affected people for ground motions 10% probability of exceedance in 50 years earthquake hazard scenario event

Ground motions 10% probability of exceedance in 50 years	
Affected Population (Daytime scenario)	55,737
Casualty numbers (Daytime scenario)	1,681 – 1,845
Affected Population (Nighttime scenario)	167,100
Casualty numbers (Nighttime scenario)	4,203 – 4,613

5.4 Risk Atlas

The Risk Atlas has been prepared as a separate document. It has a series of GIS maps prepared along with basic notes. Maps were prepared for the city showing various themes including hazards in terms of frequency, severity, and exposed elements, and vulnerability and risk.

The Risk Atlas includes:

1. Hazards (expressed as footprints of historical events and probabilistic maps of hazards for different return periods).
2. Exposure/inventory data showing distribution and valuation for various assets (residential, commercial, industrial buildings, essential facilities, and infrastructure)
3. Social vulnerability maps
4. Probabilistic loss maps by hazard
5. Probabilistic loss maps by exposure asset categories
6. Risk Maps: AAL for flood, cyclonic wind and earthquake for residential, commercial, and industrial buildings
7. Projection of losses to various sectors for flood, cyclonic wind, and earthquake hazards

6 Component 5: Capacity Assessment at Community, Ward and City Levels

6.1 Capacity Assessment of Government Institutions

The comprehensive City Development Plan for Bhubaneswar – Cuttack Urban Complex was prepared by IIT Kharagpur in 2011, which covered a detailed vision plan covering Cuttack city areas as well. The CDP emphasized economic development emphasizing land use of the region, which overlooked hazard risk of the region. The city is presently preparing its City Disaster Management Plan (CDMP). As part of the routine process, the city prepares contingency plans for flood before the onset of the monsoon and heat wave before the summer season starts. Contingency plans are prepared based on the past years' experience rather than on any forecast or scientific modeling.

The State has two recognized human resource training and capacity building institutes, namely, Gopabandhu Academy of Administration (GAA) and the State Institute for Rural Development (SIRD). These institutes provide training and capacity building for improving State resources' skills. The former focuses on training and capacity building for government officials while the latter is for Panchayati Raj Institutes (PRIs), Government officials, Non-Government Organizations, and community based organizations. In addition to this, State level organizations like the Odisha State Disaster Management Authority (OSDMA) and UN organizations also providing capacity building and skill enhancement activities for government departments and communities. The Bhubaneswar city administration, non-government organizations, and the communities also receive training and capacity building activities through these organizations.

Out of 10 Odisha Disaster Rapid Action Force (ODRAF) units, one unit is located at Cuttack municipality. ODRAF provides training for disaster response activities, such as mock drills, rescue operations on a regular basis.

One of the National Disaster Response Force (NDRF) teams is located at Mundali, Cuttack and it performs various activities related to disaster risk reduction training and capacity building from time to time in different parts of the State. Key activities include liaison, reconnaissance, rehearsals and mock drills, and imparting basic and operational level training to State Response Forces (Police, Civil Defence and Home Guards). The NDRF of the State is also actively engaged in various community-based activities including:

1. Community Capacity Building Programs
2. Public Awareness Campaigns
3. Exhibitions: Posters, Pamphlets, literatures

Apart from these organizations, Civil Defence is also present in the city to provide services like:

- Dissemination of warnings in the likely affected areas and evacuation of people.
- Management of shelters
- Extra forces during emergency as well as during festival time to manage crowd
- Rescue of casualties, restoration of essential services, repairs and clearance of roads by cutting off fallen trees and debris, salvage and properties etc.
- First Aid and Medical attention to the victims of road accidents, emergency sanitation, prevention of epidemic, and disposal of corpses and animal carcasses
- Emergency feeding, sheltering and clothing of the homeless, and
- Establishment of communication network through VHF/HF sets for easy command and control

UNDP, India is very actively involved in various DRR activities in the State since the Odisha Super Cyclone of 1999. It mainly coordinates and works closely with ODSMA and senior disaster managers in the government and supports both technical capacity building and infrastructure development for DRR.

6.1.1 Capacity Requirements of Government Institutions

The capacity requirements of government institutions need to be analyzed in the light of the nature of the hazards and their impacts on the city. One needs to evaluate whether the city, as a service provider, has adequate capacity in terms of skills and resources to support the community needs in the current and predicted future environment.

There are several dependencies between institutions and departments in the city and the State that need effective coordination.

For instance, major drains of the municipality are maintained by the Water Resource Department while the City Administration maintains the secondary and tertiary drains. Desilting and maintenance of these drains and ponds need to be coordinated to avoid water logging problems in some parts of the city. Similarly, the housing permits are being issued by CDA based on the development plan prepared, while the City Administration collects housing revenue.

During consultations with stakeholders, the following information was gathered/inferred:

1. The department is aware of the building codes and development controls for the municipality. However, there are inadequate mechanisms to monitor this on ground
2. The land use and city development is to a good extent driven by economic development and does not consider hazard risks
3. The government departments are well aware of disaster risks and have Standard Operating Procedures (SOPs) in place. However, their knowledge of the concepts of DRR and CC are not extensive. The level of awareness of the community on DRR and CC is very poor
4. The municipality has identified shelter locations. However, the city does not have updated information on the India Disaster Resource Network (IDRN) portal

In terms of capacity and needs of the municipality, the following are suggested:

1. There is a need for close coordination between the City Administration, state agencies, and urban bodies for good governance. This includes coordination with the Water Resource Department for maintenance of natural drains and drainage systems and with CDA for implementation of building codes
2. The building codes of the city need to be reviewed in light of the hazards in the region and need city-specific amendments. There should be a mechanism in the city to monitor the adherence to building codes and land use norms to improve urban resilience
3. In terms of human resources, the city needs a dedicated workforce mainly at the field level particularly for the health sector and waste management
4. City officials need training and capacity building to mainstream climate change impact into city development planning. The City Development Plans need to consider hazard risks and carry out Cost-Benefit-Analysis (CBA) of investments considering these.
5. The city officials need to be engaged by higher officials to reinforce the city official’s job roles and responsibilities. Corporate training and operational model can be imparted to improve the effectiveness and efficiency of the officials in gathering knowledge and performing their duties
6. The city needs epidemic contingency plans and long term plans for the health sector taking climate change impacts into consideration
7. A mechanism for enforcing registration of disease cases (with their locations) and mortality through all government and private hospitals can help in developing strategies for the health sector. There should be a mechanism for registering diseases in the city similar to birth and death registrations.
8. As part of decongesting the core city area, long term plans need to be adopted by the municipal administration. This includes identifying pockets in the outskirts for

development, thereby regulating new construction in city center, and implementing incentive and disincentive mechanisms for people to move towards the outskirts. The incentives and disincentive can be in the form of property tax rebates in the outskirts and additional core city taxes in the city center. While taking this effort, the identified location needs to be planned well in terms of proper structural measures to ensure that these locations are disaster risk resilient.

9. Aligning to the digital drive in India, the municipality should also encourage and enforce e-business in the traditional market areas in the municipality. This will not only help these business establishments to operate from the outskirts and decongest the core city area but will also make business transactions more transparent and generate income to the government in the form of tax collections.
10. Being a revenue poor local body, the municipality needs a plan to generate revenue to meet its expenditure and provide better services. In addition to the traditional income generation means, including property taxes, leasing, renting and selling of municipality assets, innovative mechanisms need to be developed.
11. Crowd sourcing methods for managing efficient service delivery is also an option for low revenue local bodies. For instance, solid waste management, water logging, and flooding are key problems. Clogging of drains and silting of ponds are key problems caused due to ineffective solid waste management. Effective crowd source models can be applied at least in the crowded commercial areas. The Municipality needs to coordinate with merchant associations and engage groups of shops in each lane to contribute and take the responsibility of collecting solid waste in their respective lanes. This will not only reduce the revenue burden of the municipality but also help develop responsibility of maintaining clean streets in the shop owners. This can reduce the flood and water logging problem to a good extent.

Note: the above mentioned suggestions are towards addressing the developmental issues but will also improve the economic and social resilience of the communities, which will help in reducing the vulnerability of the municipality to natural hazards to a good extent

6.2 Capacity of Social Institutions

6.2.1 Community Capacity and Awareness

OSDMA, UNDP, and similar organizations have put efforts in increasing community awareness on DRR and its impact on the city. However, community behavior needs major change particularly in the areas of construction of residential structures and disposal of solid waste. The communities need to work on these two critical areas to improve city resilience.

Strictly regulating the development of new slum pockets is essential for the municipality to achieve its vision to develop the municipality as a slum-free entity. This needs awareness of the elected representatives and they should be the key messengers and implementers of this task.

To improve the capacity of communities, the following measures are suggested:

1. Community awareness focusing on DRR, CC, hygiene, sanitation, is required. Community organizations, Self-Help Groups (SHGs) need to be identified and trained to train the communities to work in the health sector.
2. Communities need to be sensitized on the importance of adhering to land use, building codes and hazard zones. NGOs and elected representatives need to be involved in the process of community sensitization.
3. Emphasis on sensitizing programs on nutrition and prevention of epidemics is important particularly in the highly vulnerable and crowded wards of the city.

7 Component 6: Priority Areas for Risk Reduction and Action Plan to Build Resilience

7.1 Existing Strategies of the City in Disaster Risk Reduction

The Odisha State has declared zero tolerance to life loss to disaster and has taken several remarkable initiatives toward disaster risk reduction at the State and local administration levels. The State has aligned its DRR strategies in-line with the national DRR strategies. The State and district-level DM plans are in place and they are presently the city administration is preparing the city level DM plans. This needs to be endorsed by all stakeholders (line departments) and put in action.

The City has its contingency plan for monsoon, heatwave, cyclone hazard, and crowd management during festival gathering. Volunteers are available for support and activities are coordinated by OSDMA. The city is also developing the Early Warning Systems (EWS) as part of the DRR initiatives.

7.2 Approach to Disaster Risk Reduction Action Plan

The disaster risk reduction action plan emphasizes on four key components of disaster management – prevention and mitigation, preparedness, response and rehabilitation, and build back better.

Figure 7-1: Typical DRR framework

To reinforce these components, several initiatives are required in the case of Cuttack city. These include:

Prevention and mitigation

1. Applied research: Need applied research in safe disposal of solid waste as solid waste is one of the key issues for flooding and water logging problems in the city. The State has an IIT and other educational institutes, which can take a lead in collaboration with national and international universities to explore possibilities of solid waste recycling and incineration.
2. Policy interventions: Need review of the building bylaws and make necessary updates based on the hazards in the city. This include, developing and implementing an effective mechanism for development controls and automated mechanisms for monitoring and approval of building permits is needed. This can be done through an automated mobile phone based application instead of physical inspection of the location. The building

owners can upload the images of their buildings and can be screened through a centralized system with fewer human resources and costs. This will also have the advantage of transparency and efficiency.

3. Structural measures: additional structural interventions are required to reduce the flood impact in the city by connecting secondary and tertiary drains to the present ongoing primary storm water drains being constructed under the JICA funded program.

Preparedness

1. Identification of risk zones: As part of the present HRVA studies the risk zones for various hazards are mapped and these zones need monitoring and priority interventions.
2. EWS: the EWS developed should reach communities in the risk zones and should address flood and cyclone hazards.
3. Awareness: community awareness on disaster preparedness and response for vulnerable communities particularly slum areas and communities living in flood vulnerable locations is required. Awareness for residential and commercial communities on safe solid waste disposal is required to avoid clogging of drains that leads to water logging and flooding.
4. Business continuity plan: Being the commercial hub of the state, a business continuity plan needs to be in place to avoid disruption of business in case of flood and cyclone events, which occur in specific months of the year.

Response

1. Safe shelters: Signage of safe shelter and flood water marks need to be displayed in public places in local language and English.
2. Information on equipment: The State IDRN list needs to be updated on a regular basis and the contact information needs to be validated so that this can be used during emergencies.
3. Contingency plan: The contingency plans for flood, cyclone, heat wave, and crowd management need to be reviewed periodically and after any major event to see if or where any improvements are required.

Rehabilitation and build back better

1. Financing: There are several sources of climate funds that can be tapped for developing climate resilient infrastructure. This can be achieved through mainstreaming DRR and CC in development activities.
2. Insurance: Insurance of assets - residential and commercial buildings - needs to be encouraged against natural hazards – flood, cyclone, and earthquake.

The below matrix provides action plan road maps for some priority interventions for Cuttack City.

7.3 Structural Measures: proposed interventions

Table 7-1: Proposed interventions: structural measures action matrix

Priority measures	Nature of vulnerability that can be addressed	On-going development activities and residual risk	Possible implementing agency	Program priority
Hazard: Flood and water logging				
Revive natural and complete artificial urban drainage system	Reduce urban flooding, reduce water logging and control vector-borne diseases	JICA projects cover part of the drainage system of the city. Need to revive the drains not covered under this programs	H&UD	High
Revive city water bodies such as temple ponds and natural tanks as temporary holding ponds and integrate them into the natural drainage system	Reduce flooding/ water logging, control vector-borne diseases, revive cultural heritage	Cuttack has a large number of ponds that are silted. Efforts were made for conservation of ponds under various programs. JICA project has identified 17 ponds for restoration. But only one pond is considered for renovation under this program. Need de-silting to utilize the capacity of these ponds.	CMC	High
Risk-sensitive urban development in implementing the Master Plan	Address urban flood issues for urban development in the city	Risk sensitive land use planning was not considered in the Master plan	CDA	High
Local level solid waste management strategies	Reduce urban flooding, reduce water logging by improving functioning of drainages, and control vector-borne diseases	Parts of city are covered under city services. Inadequate collection and handling capacity.	CMC	High
Storm water network for tertiary drains	Reduce urban flooding, reduce water logging, and control vector-borne diseases	Not attempted under any project. The choking of tertiary and secondary drains leads to local flooding/water logging.	CMC	High
Hazard: Cyclone				
Enumeration of trees and planting of native trees, which can withstand cyclone winds	Reduce loss of life and damage to assets during cyclone winds	Not attempted under any project	Department of Environment and Forest	Low

Priority measures	Nature of vulnerability that can be addressed	On-going development activities and residual risk	Possible implementing agency	Program priority
Design cyclone resilient pucca houses under national and state housing programs	Damage of residential houses particularly in slums and reduce causality	Attempted under some national flagship program though not adequate	CMC	High
Hazard: Multi hazard (cyclone, earthquake and flood)				
Assess vulnerability of life-safety and other essential facilities	Reduce risks from all three hazards – cyclone, flood, and particularly earthquake	Not attempted under any project	OSDMA	Medium
Rehabilitation of vulnerable slum pockets	Reduce loss of life and livelihood. The city has about 40% of people living in slums.	Carrying out rehabilitation of slums under different centrally sponsored projects Inadequate to address the needs, considering the housing demand and growth in slum population	H&UD	High
Retrofitting of lifeline facilities, including hospitals and schools	Reduce life loss, and damage risk from earthquake hazard	Not attempted under any project	H&UD	High
Vulnerability assessment of heritage structures	Helps to take proactive measures to protect heritage structures from all three hazards	Not attempted under any project	Tourism department	Low
Restoration and retrofitting of heritage structures	Reduce risk from earthquake hazard	Not attempted under any project	Tourism department	Low
Decongestion of millennium island and reconstruction of old city high density vulnerable areas	Reduce loss of life from all three hazards and health hazards	Not attempted under any project	H&UD	High
Developing a safe drinking water supply network to reduce contamination and epidemics	Reduce adverse health impacts, loss of life from all three hazards particularly during flood events	Under routine city development activities. Inadequate to address the capacity	H&UD	Medium

7.4 Non-structural Measures: proposed interventions

Table 7-2 Proposed interventions: non-structural measures action matrix

Priority measures	Nature of vulnerability that can be addressed	On-going development activities and unaddressed future risks	Possible implementing agency	Program priority
Update building bylaws and development control regulations to incorporate CC and hazard risks	Reduce vulnerability and risk to cyclone, flood, earthquake, and heat wave. Also, save energy.	Not attempted under any project	H&UD	High
DRM plans at community level, particularly in vulnerable pockets	Reduce vulnerability and risk to cyclone, flood, earthquake, and heat wave.	Carried out community awareness activities under UNDP program (2009) Need continuous awareness activities especially in health and hygiene	OSDMA	Medium
Incorporate hazard risk and CC impact in slum rehabilitation programs, including location identification housing design and development of infrastructure, etc.	Reduce vulnerability and risk to cyclone, flood, earthquake, and heat wave.	Not attempted under any project	OSDMA	Medium
Incorporate risk-sensitive land use planning and development control in city master plans	To address urban flood issues for the city	Not attempted under any project	CDA	High
Develop effective enforcement mechanisms for building bylaws and development control regulations	Reduce vulnerability to cyclone, flood, earthquake, and heat wave.	Not attempted under any project	CDA	High
Automated system for approval building permit	Foolproof and efficient approval system, improve structural resilience to disaster	Not attempted under any project	H&UD	Medium
Development of digital data policy to share data developed in various projects and to avoid recreating of data each time.	Improve efficiency (cost and time) in urban planning and developing resilience	Not attempted under any project	Information technology department	Medium
Development of Urban transport policy for efficient transport planning	Improve transportation network, improve energy efficiency in the transport sector, and reduce road accidents	Not attempted under any project	CDA	Medium

8 Annexures

8.1 Annexure 1: Methodology used for Hazard, Exposure, Vulnerability and Risk Analysis

8.1.1 Cyclone Hazard Assessment

Surface wind field associated with a tropical cyclone was derived using a dynamic storm model (Jelesnianski and Taylor, 1973). The model uses the pressure drop, forward speed, and radius of maximum winds of historical cyclonic storms as inputs and simulates wind speeds at model grid points of resolution 250 m x 250 m. Many important historical events have been used to calibrate the model in terms of pressure drop, which plays a fundamental role over the wind speed for the episode. The storm model was then validated against available observed data of wind speeds.

Further, the validated storm model was used for simulating the peak wind speeds associated with historical cyclonic events that passed in and around the city during 1877-2016. The Gumbel (1954) extreme value probability distribution was applied to the modeled wind speeds at each grid point of the model domain and maximum wind speeds for key return periods (2, 5, 10, 25, 50, 100, 250 and 500 years) were estimated. These return period scenarios of wind speeds are being considered as wind hazard scenarios at present climate.

This output of the cyclone hazard analysis is used for assessing location specific vulnerability and risk associated with cyclonic/strong winds.

Calibration and validation of the storm model: Model was validated against many historical events wherever observed values of wind speeds were available. Storm model results are compared in Table 8-1 for two famous historical events – 1999 Odisha super cyclone and 2013 very severe cyclonic storm Phailin. The percentage error between observed and computed values of wind speeds exhibits a good agreement with maximum of 2.7%, which indicates that the numerical solutions represent a realistic distribution of wind fields in the study region.

Table 8-1: Validation of wind speeds for 1999-Odisha and 2013-Phailin cyclones

Cyclone name and year	Observed peak gust (km/h)	Modeled peak gust (km/h)	Error in % between observed and modeled peak gust
25-31 October 1999 Odisha Super cyclone	260	267	2.7
5-14 October 2013 Phailin cyclone	215	219	1.8

Cyclone Hazard Analysis for Present and Future Climate: Wind hazard maps were produced based on wind speeds derived from the storm model for different return period events under present climate scenario and two future climate scenarios based on climate change. The map shows the distribution of intensity throughout the city. Levels of hazard classes were assigned for hazard maps by the specific wind speed ranges.

Wind hazard maps for historical cyclonic events: Wind hazard maps for historical events were prepared by integrating modeled wind speeds with various GIS themes to produce maps with varying wind magnitudes. The modeled wind fields of peak wind speeds associated with 1999 Odisha and 2013 Phailin cyclones are shown in Figure 8-1 and Figure 8-2.

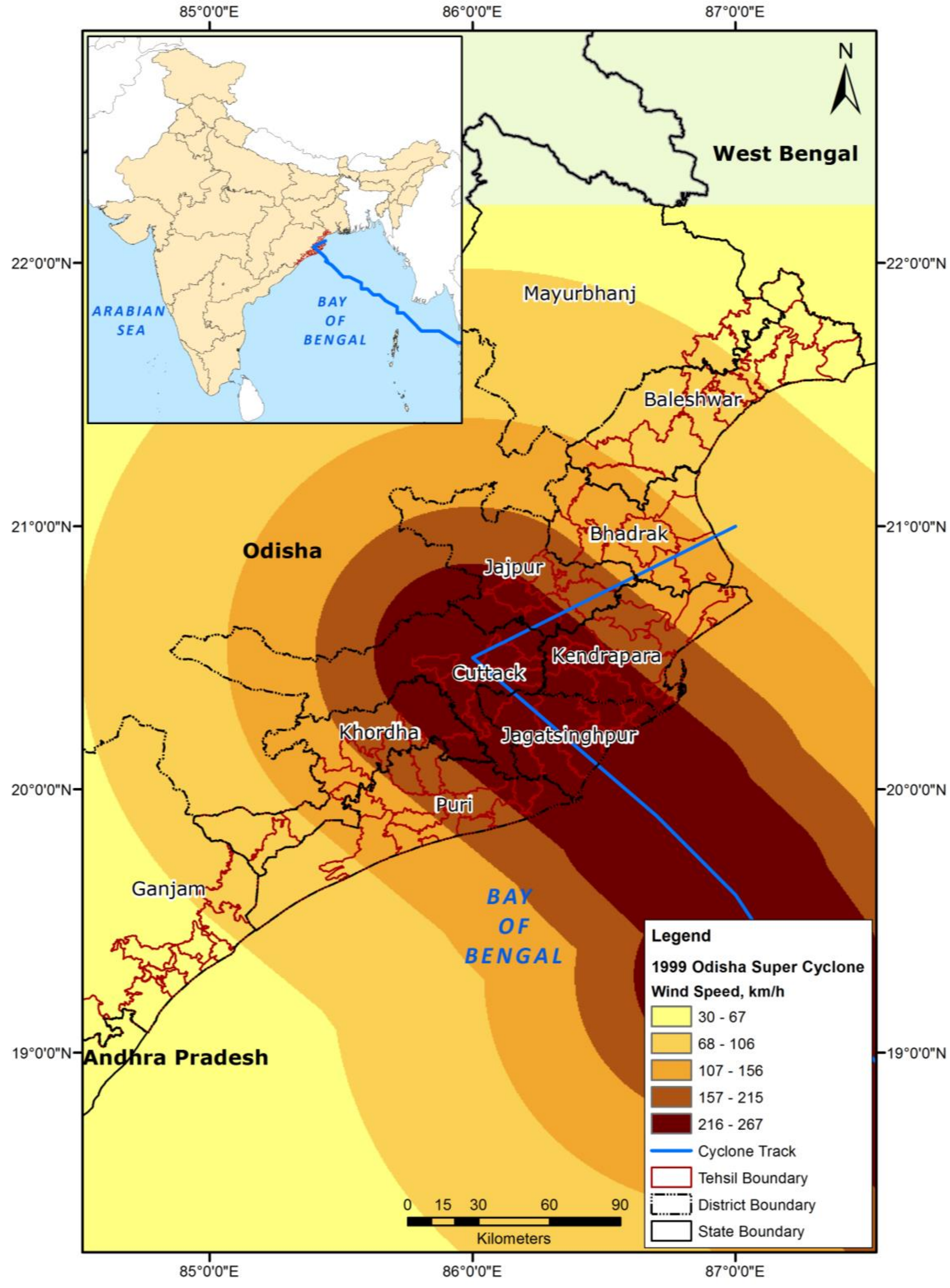

Figure 8-1: Modeled wind field of 1999 Odisha Super Cyclone

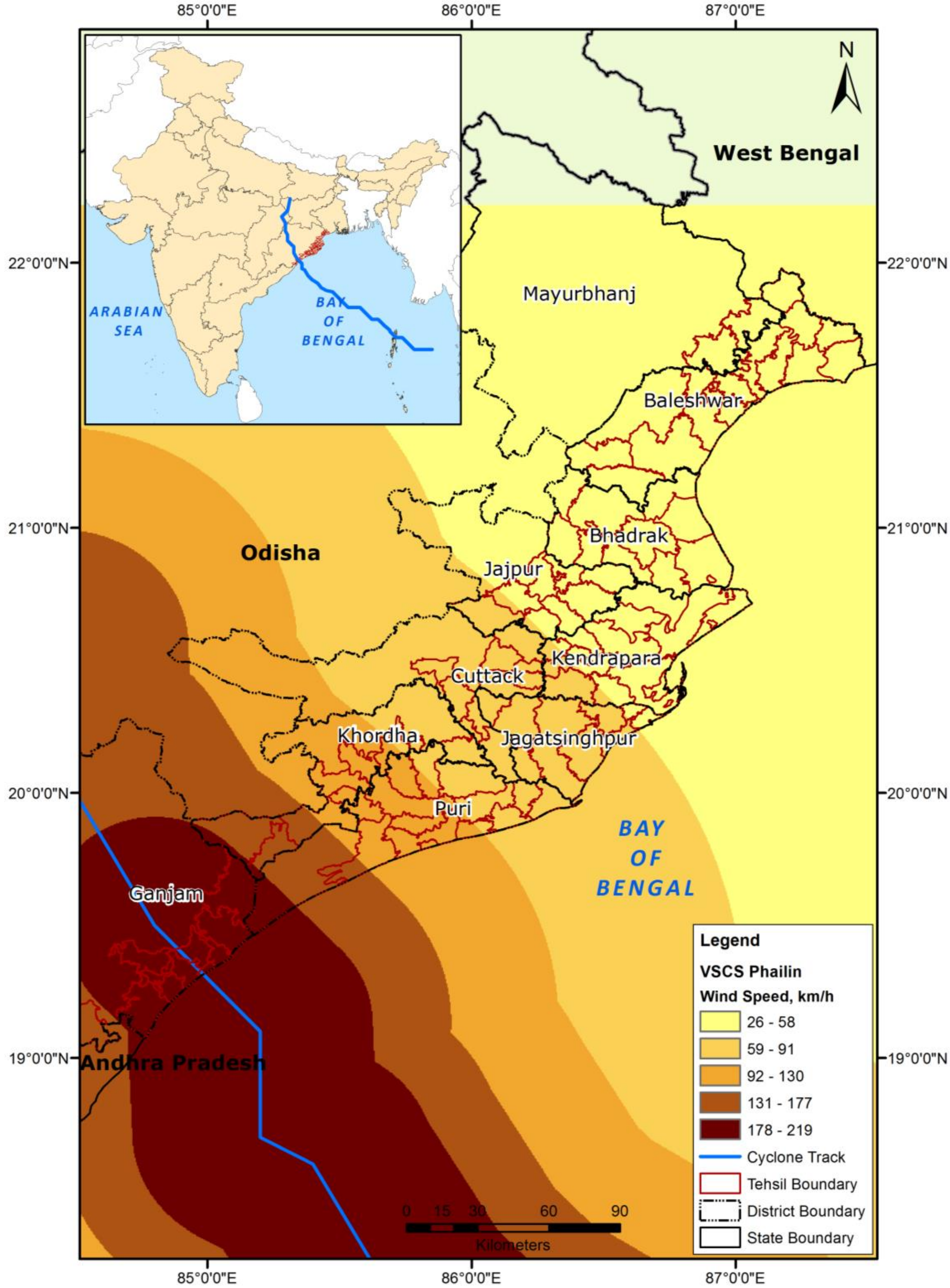

Figure 8-2: Modeled wind field for 2013 VSCS Phailin

8.1.2 FLOOD HAZARD ASSESSMENT

The city is situated at the confluence of two big rivers, namely, the Mahanadi in the north and the Kathajodi in the south, which make it highly prone to the flood hazard. The topography of the city is shaped like a saucer, with the central part at a lower elevation than the peripheral. It is surrounded by embankments, which protect it from flooding. The high ground elevations, which are towards the banks of the rivers, are MSL + 30m in the north and MSL + 20m in the south and the east of the city. The central part of the city has an elevation of only about MSL+17 m.

Primarily the city gets flooded due to heavy rainfall locally as well as in the upstream catchment areas and the release of high discharge from Hirakund dam located 330 km upstream.

In earlier times, the city had many ponds, which used to retain and moderate storm water runoff into the drain. These ponds were eventually filled partially and became low-lying areas with little scope for natural drainage. Besides, the slope of land is mostly away from the river making natural drainage difficult. The only practical way to prevent flooding from water logging is using water pumps that have been installed at the various locations in the city.

In the past, the Mahanadi Basin has experienced high floods in 1982, 2001, 2003, 2006, 2008, and 2011.

Assessment of localized flooding due to flash flood/water logging: Ward No. 2, 3, 9, 14, 17, 20, 26, 33, 40, 43 are especially prone to water logging due to the low-lying nature of the land. In the newly expanded areas, there is no proper drainage system. Inside the city, due to its topographical characteristics and disposal of solid waste materials in the drain, storm water drain is a serious concern.

The problem becomes serious when flood water levels in the two major rivers are above the water levels in the drainage channels and the pumping capacity is not sufficient to pump out the water. During such times, many areas in the city remain water logged while low-lying areas are inundated. These conditions cause serious public health and safety problems for the city residents.

For understanding the nature of localized flooding, floodplain mapping has been carried out for the city. As a first step in the analysis, the city has been divided into smaller catchment units contributing to the drains of the city. The catchment delineation has been done using the HEC-GeoHMS 4.2 tool. HEC-GeoHMS 4.2 is an extension application that supports identification of the river network and division of the catchment (basin area) into a number of sub areas.

In the second step, design discharges for each catchment have been carried out. For design discharge estimation, the Detailed Project Report (DPR) prepared under the JICA funded project was taken as a reference. JICA[6] has done an intensity-duration-frequency analysis of the rainfall pattern of Cuttack City. They have used rainfall data for the rain gauge station at Naraj from 1988 to 2007 (a duration of 20 years). Table 8-2 summarizes return period rainfall data for Cuttack city.

Table 8-2: Return period daily rainfall for Cuttack City (Source-JICA DPR)

Return Period (Yrs)	Daily Rainfall (mm)
2	108
5	170
10	216
25	282
50	337
100	397

As the next step, the time of concentration and catchment areas of each drainage line have been calculated. The rainfall intensity corresponding to the time of concentration duration has been used. For the estimation of rainfall intensity for selected duration, time distribution curves

[6] Detailed Project Report for Drainage System in Cuttack City under JICA Assisted Odisha Integrated Sanitation Improvement Project (ID-P187)

were used from Mahanadi Basin PMP atlas[7].The larger the area, the longer the time of concentration and the lower is the intensity. Using this design rainfall intensity for selected duration, the catchment flows have been estimated using rational formula.

The Rational Method is an empirical equation that derives the peak runoff from a tributary area based on a runoff coefficient, rainfall intensity, and area.

Discharge Q= CIA, where

Q = Peak discharge corresponding to peak intensity, m^3/s

C = Runoff coefficient, function of the soil type and drainage basin slope

I = rainfall intensity corresponding to the duration equivalent to the time of concentration

A = Catchment area

The return period flow estimates using the rational formula are used as an input in the hydraulic model.

Hydraulic modeling (inundation model): The main purpose of hydraulic modeling is to route the flows from one location to another, while estimating water surface elevations and profiles for various scenarios. Generally, the flows or water surface elevations observed at a particular location are given as inputs to the model along with channel characteristics such as cross-section, slope and roughness. Alternatively, flows estimated in hydrologic modeling provide an input to the hydraulic model. The 2D hydraulic model developed by USACE, namely, Hydrologic Engineering Centre's River Analysis System (HEC RAS) is used for predicting and understanding the inundation processes in the floodplain.

The broad outline of the methodology adopted for hydraulic modeling is as follows:

- Generate or acquire Digital Elevation Model (DEM) of the area of interest
- Convert the DEM into floating point raster grid for mesh generation
- Create the river and floodplain terrain model using the raster grid/grids
- Create a spatially varied Manning's roughness layers using land use dataset (optional)
- Associate the terrain model and Manning's Roughness layers with the geometry data
- Define the river and floodplain 2D flow area boundaries
- Generate the 2D mesh area using the appropriate cell size for river and floodplain
- Refine the generated mesh for any ambiguity and shape
- Define the upstream and downstream boundary conditions along with other parameters
- Simulation of design flows
- Calibrate the model using the historical high flood water levels and flood extent maps
- Visualize and interpret results

Incorporation of hydraulic structures: Structural river training plans are traditionally known methods of flood mitigation and this method has been used as a general flood management approach in most of the flood plain areas. These hydraulic structures have proven effective in loss reduction due to floods. However, in the case of Cuttack City these structures benefit partially.

Dykes/Levees or Retaining Walls: Most of the areas of Cuttack City are protected by well-maintained embankments from both sides of the city from Kathajodi and Mahanadi rivers. However, some parts of the city continue to be ravaged by riverine flood. Flood embankments have been incorporated in the hydraulic model to demarcate the flood boundaries of flood plains.

[7] http://www.cwc.gov.in/main/downloads/Mahanadi%20Basin_volume-I.pdf

Barrages and Diversion Channels: The Naraj Barrage has been constructed on the Mahanadi River upstream of Cuttack City to protect the city from upstream flooding. Flows in the Kathajodi and Mahanadi rivers are distributed in 40:60 ratio for total discharges up to 20,000 cumecs. As the discharge increases beyond this limit, the flows are divided in a 50:50 ratio in both the rivers.

Sluice Gates: Cuttack City currently has two main drains along with their tributary drains. The main drain 1 caters to flows from the central and western part of the city and discharges into Kathajodi River. Similarly, main drain 2 caters to flows from the eastern part of the city and discharges into the right bank Mahanadi River. To prevent the back flow of the river's water from entering into the city during floods, these drains are controlled by sluice gates at their respective discharging ends. The operation of the sluice gates on the drains in the city is based on the total flow in the Mahanadi River at the Mundali Barrage. These gates are manually operated and in general takes 3 to 4 hours to start operation.

In normal conditions, all the sluice gates remain in operation. However, during the monsoon season when the flows increase over a particular threshold discharge at Mundali these sluice gates are closed to prevent flooding.

Pump Stations: When the sluice gates on both the main drains are closed, drainage water is choked within the city. This causes serious flooding in the outlet areas of the drain. In addition to this, flooding in the low-lying areas is very common in Cuttack City as flood and rainwater accumulates in these areas without appropriate outlets. Water pumps have been employed to pump out water from such areas. The details of water pumps have been incorporated in the hydraulic model along with their pump head efficiency curves to analysis the impact of flooding.

Flood Hazard Assessment for Current and Future Climatic Conditions: Flood hazard assessment helps to demarcate the flood-prone area (extent), and assess its intensity and magnitude. Flood-prone areas are those areas subjected to inundation with regular frequency. In the case of Cuttack city, riverine flood hazard is considered and the framework adopted is given in Figure 8-3. The key components include:

- Identification, acquisition, compilation and review of all the relevant hydro-meteorological and biophysical data. These data include terrain, soil, land use land cover, runoff/river discharge and flood protection measures to form the input for the model.
- For the assessment of localized flooding, delineation of drainage flow lines within the city boundary
- Probabilistic analysis of runoff to simulate various return period events (from frequent to rare events) for Tikarapara flow gauge station upstream of the city.
- For the city area, analysis of design storms and estimation of return period flows using rational formula.
- Hydraulic modeling to estimate flood levels throughout the basins for various flows generated from key return period events
- Flood hazard mapping to show flood extent and flood depth for a range of events, which is the result of hazard assessment.

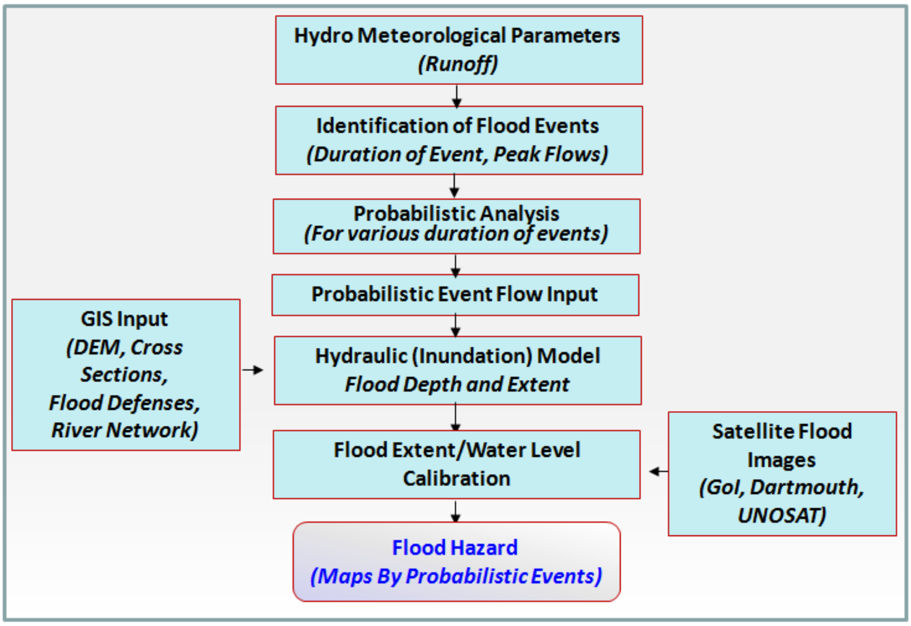

Figure 8-3: Flood hazard assessment framework

Probabilistic simulation of runoff: Probabilistic simulation is necessary due to non-availability of historical observations for long periods. Generally, historical observations are available for a relatively short period (say 20 to 50 years). Probabilistic simulation helps in generating events to capture extremes that might not have been present in the available historical datasets. Probabilistic event sets have been generated using river discharge/runoff data at Tikarapara flow gauge station located upstream of the Cuttack City and Naraj Barrage. The annual maximum flows have been presented in Figure 8-4. The probabilistic flow discharge at key return periods (2, 5, 10, 25, 50, 100 years) have been estimated and are given in Figure 8-5. These sets of probabilistic event flows have been given as inputs to the hydraulic model for determining flood extents for each probabilistic event.

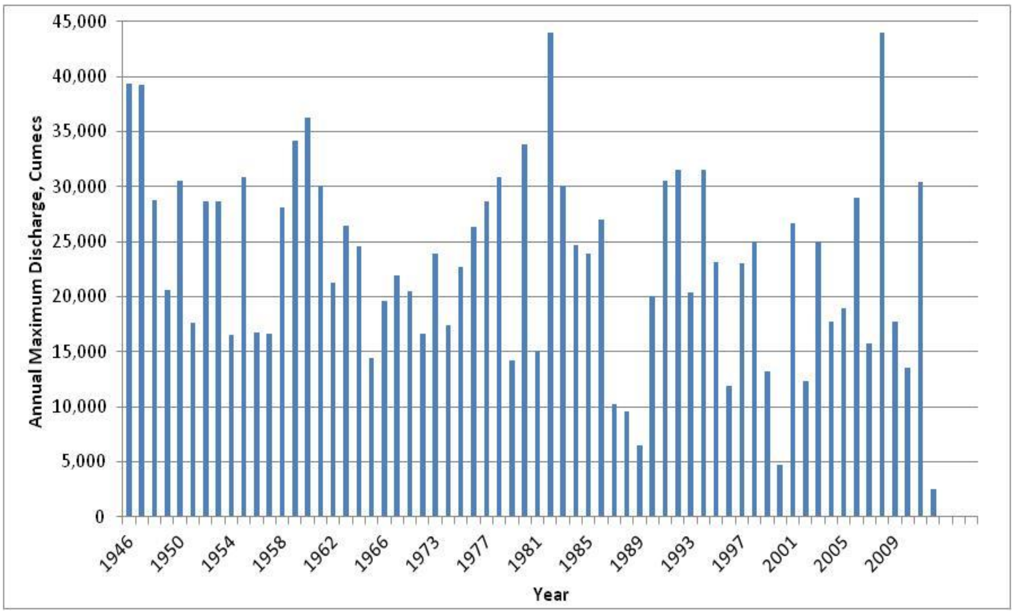

Figure 8-4: Annual Maximum Discharge for Tikarapara Flow Gauge Station

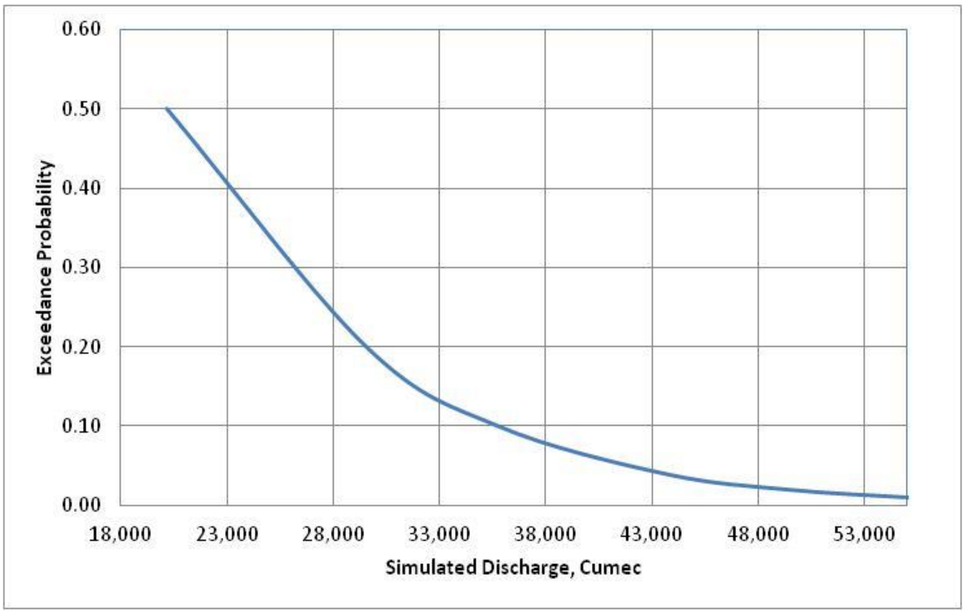

Figure 8-5: Simulated Return Period Discharges at Tikarapara

8.1.3 HEAT WAVE ANALYSIS

Historical weather data was collected from the India Meteorological Department (IMD) and other available sources to analyze the rising trends in surface air temperature and also assess the trend in monsoon rainfall in Cuttack district during the past few decades.

Temporal trends in daytime maximum and night time minimum surface air temperatures and rainfall were assessed using historical weather data.

As per Seismic Zoning Map of India (IS: 1893, 2002, 2014), Cuttack city is located in seismic zone-III. Cuttack and its surrounding regions lie in a Stable Continental Region (SCR) that is not seismically very active. However, minor to moderate earthquakes not of damaging scale have occurred in the past at different localities. In the recent past, the maximum magnitudes reported are around 4.5 to 5.3 on the Richter's scale and the maximum-recorded intensity in Cuttack city so far is about VI on the MSK Intensity scale. In spite of the moderate, non-damaging earthquakes observed so far in and near Cuttack, it cannot be confidently said that higher intensity earthquakes are unlikely. Recently, on May 21, 2014, an earthquake of magnitude 6 occurred in the Bay of Bengal, which was severely felt in different parts of Cuttack city. However, there was no significant damage reported in the city.

Seismic hazard assessment identifies and demarcates areas, which are exposed to different levels of earthquake ground motion. It provides information on the expected levels of peak ground motion that might be experienced in different parts of a city for a particular value of probability of exceedance by taking into account all the seismic sources in and around the city. Most of the seismic hazard assessment studies estimate the expected hazard at hard rock level. However, it is important to know that ground motion experienced by structures is not necessarily at hard rock level, and hence should be estimated at the surface level. Since, local soil also plays an important role in ground motion amplifications, especially when Vs30 (average shear–wave velocity up to a depth of 30 meters) values are much lower 760 meters/second. From the data analysis, it was observed that Vs30 values in Cuttack city vary from about 180 m/sec to 410 m/sec. Hence, for proper estimation of seismic hazard, modeling of local soil amplification is important. The seismic hazard assessment approach for Cuttack city comprises of the following:

- Review of published probabilistic seismic hazard analyses for key return periods and choose the hazard value(s) at hard rock level

- Model the soil-amplification on a finer grid cell of 0.1 km x 0.1 km using NEHRP (2007)/HAZUS-MH soil classification scheme
- Convolute the hazard value(s) at hard rock level with soil amplification factors and generate earthquake hazard maps for 10% probability of exceedance (475 year return period)
- Compute the seismic hazard values at Uniform Resolution Grids (URG) at 0.1 km x 0.1 km for Cuttack city
- Generate GIS based seismic hazard maps at ward level
- Seismic hazard mapping to show expected peak ground motion (Peak Ground Acceleration, PGA) of 10% probability of being exceeded in 50 years (475 year return period), which is the end result of hazard assessment.

Methodology for Climate Modeling and Analysis of Extreme Weather Events

Surface temperature is projected to continue rising under all assessed emission scenarios and that heat waves will occur more often and last longer, and extreme precipitation events will become more intense and frequent in many regions. In longer time scale, oceans will continue to warm and acidify, and global mean sea level would rise resulting in large-scale coastal inundations and salinity intrusion in coastal areas. Warming may induce sudden shifts in regional weather patterns that would have severe consequences for water availability and threaten the livelihoods of millions of people across the world (IPCC, 2013).

The negative impacts of climate change will be disproportionately felt in developing countries such as India that still have a large rural population dependent on rainfed agriculture. Climate change-induced effects in India are expected to have a far-reaching regional impact on fresh water resources as the country forms a major source of fresh water and drainage areas extending into the Bay of Bengal and Arabian Sea regions. This is because vulnerability to climate change is a factor of exposure, sensitivity and adaptive capacity.

Historical surface warming in Cuttack: The historical warming trend over Cuttack district in Odisha is illustrated in Figure 8-6.

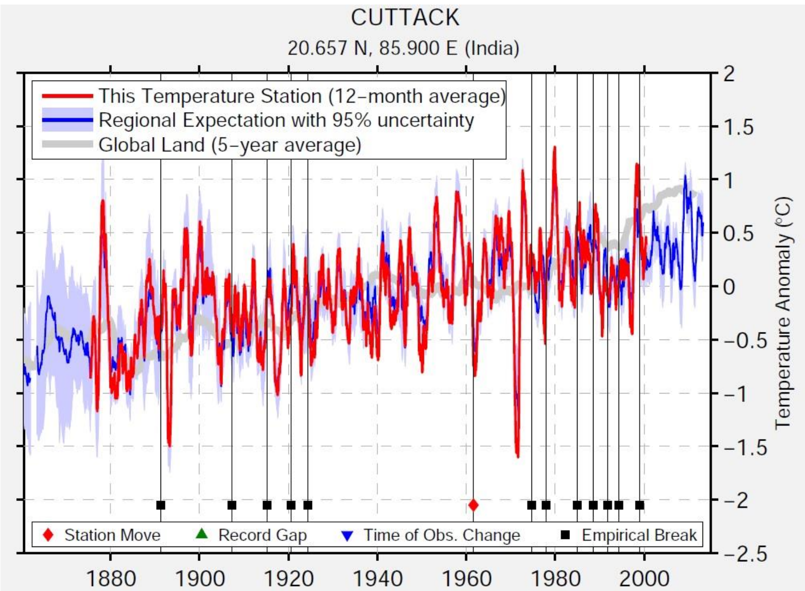

Figure 8-6: Historical trend in temperature anomalies as observed over Cuttack in Odisha (Source: Berkley Earth Surface Temperature Data)

Climate model validations and downscaling of simulated data: The downscaled climate scenarios for the globe that are derived from the ESM runs conducted under the Coupled Model Inter-comparison Project Phase 5 (CMIP5) are available as NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP, 2015) dataset. The Bias-Corrected Spatial Disaggregation (BCSD) method has been applied to produce downscaled CMIP5 climate projections for its use at country, province or local level assessment of climate change impacts. This approach used in generating the downscaled dataset inherently assumes that the relative spatial patterns in temperature and precipitation observed from 1950 through 2005 will remain constant under future climate change. Other than the higher spatial resolution and bias correction, this dataset does not add information beyond what is contained in the original CMIP5 scenarios, and thus preserves the frequency of periods of anomalously high and low temperature or precipitation (i.e., extreme events) within each individual CMIP5 scenario.

The RCP 8.5 scenario dataset was used for deriving daily scenarios under CMIP5. Each of the climate projections includes daily maximum surface air temperature, minimum surface air temperature, and precipitation for the periods from 1950 through 2100. This dataset facilitates in conducting climate change vulnerability assessment and sector specific impacts at local to regional scales, and thus to enhance our understanding of possible future global climate patterns at the country, province or local spatial scale. Each of these climate projections is downscaled at a spatial resolution of 0.25 degrees x 0.25 degrees (approximately 25 km x 25 km). The key climate variables include daily maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2005 ("Retrospective Run") and from 2006 to 2100 ("Prospective Run"). During the downscaling process, the retrospective simulations serve as the baseline data and are compared against the observational climate records. We have extensively used the downscaled data sets in this study.

Before any downscaled data can be ingested into estimating the specific impacts of climate change over a country or region, we need to validate the performance of the models in simulating the historical climatology to attain a degree of confidence in simulations for the future. We have identified three out of nine better performing global climate models over south Asia (Indian sub-continent) and evaluated the model-simulated near surface air temperatures and rainfall for Cuttack and compared these with the average monthly observed climatology (IMD Gridded data and also CRU climatology) for the baseline period of 1961-1990. The standard deviation of model simulated surface air temperature and rainfall over Cuttack are compared with CRU (Climate Research Unit, Norwich-UK) and IMD rainfall and temperature climatology for the period 1961-1990 to examine the skill performance of these models in simulating the seasonal and annual cycle of surface air temperature. For precipitation, RMS errors in the model simulations of annual/seasonal cycle and correlation with observations have been analyzed to obtain the skill score. The simulations of daily intensity of rainfall is also analyzed to finalize the choice of the selected ESMs to be adopted in this study as most appropriate for obtaining climate variability and climate change scenarios at a time scale of a century or shorter.

A comparison of 30-year climatological (1961-1990) monthly mean surface air temperature inferred from (IMD) and Climate Research Unit (CRU), UK gridded data sets and that computed as ensemble mean of three global climate models over Cuttack is depicted in Figure 8-7 below. Figure 8-8 depicts comparison of climatological monthly total rainfall over Cuttack inferred from IMD and CRU, UK gridded data sets and that computed as ensemble mean of three global climate models. It should be noted that the model simulated monthly mean surface air temperatures are close to observed climatologies for Cuttack (largest monthly departures are within ±1ºC and annual mean departure is 0.5ºC). Figure 8-8 suggests that model-simulated monthly rainfall is able to reproduce the observed seasonality over the city. It should also be noted that models underestimate the present-day climatological monsoon season monthly rainfall totals as against observed climatology. In August (total monthly rainfall is about 320 mm), the model-simulated deviations are about -13%. The models, however, also underestimate the winter season rainfall (<10 mm/month) when the departures from IMD climatology are large (-40%). Given the fact that winter rainfall over Cuttack is markedly lower relative to monsoon season rainfall, this departure may be regarded as insignificant.

The analysis presented in the above paragraph suggests that there is a fair degree of skill in the selected models for simulations of present-day climatology at regional/local scale.

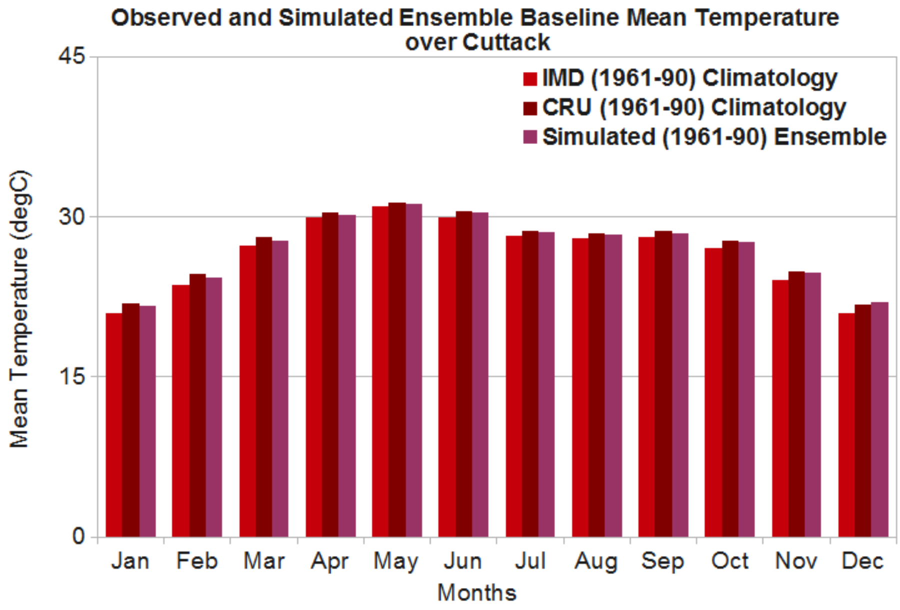

Figure 8-7: Comparison of mean monthly surface air temperature of observed and model simulated ensemble over Cuttack, Odisha

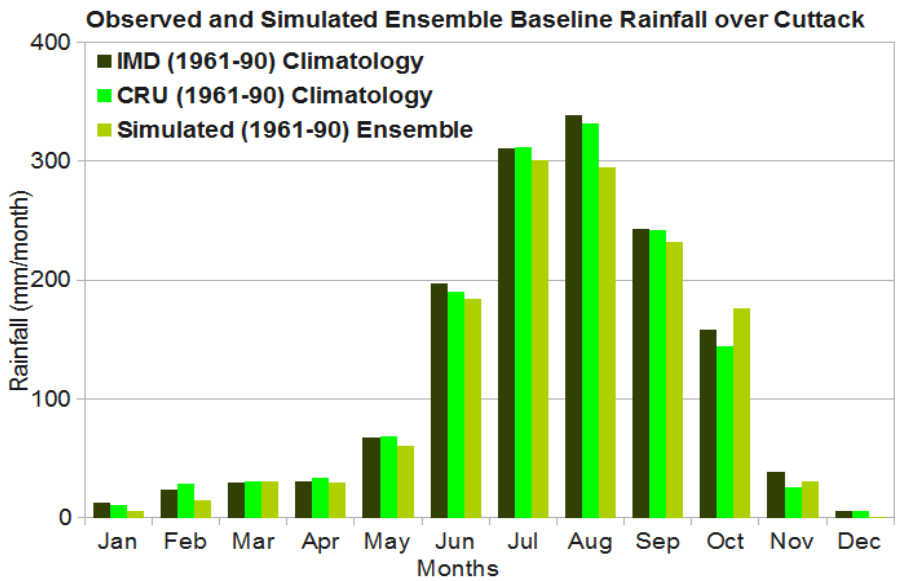

Figure 8-8: Comparison of mean monthly total rainfall as observed and model simulated ensemble over Cuttack, Odisha

Regional / local climate change scenarios: We have attempted to update the future projections based on three[8] of the best performing state-of-the-art Earth System Models (over Cuttack in Odisha state). The dataset used for inferring these projections include those generated under RCP 8.5 scenario for which daily model simulated gridded surface maximum and minimum air temperature and precipitation data were produced under CMIP5 (Taylor et al., 2012) and used in IPCC 5th Assessment Report (IPCC, 2013). In the current scenario of uncertainty[9] in global agreement on mitigative actions for restricting the greenhouse gas

[8] MPI-ESM-MR: Max Planck Institute for Meteorology, Hamburg (Germany) Model; MIROC-ESM: National Institute for Environmental Studies Japan ESM; and GFDL-CM3: Geophysical Fluid Dynamics Laboratory, Princeton (USA) Model
[9] More than 100 countries have ratified the Paris Agreement as of Nov 4th, 2016 when this treaty became operational. However, target of stabilizing the emissions at 2°C is still far away

emissions, the RCP 8.5 (Meinshausen et al., 2011) represents the most plausible global concentration pathway range for the future. Moreover, since policy makers and decision makers at country level and at municipal level in any developing country are interested in the higher end of the possibilities in the vulnerability due to future extremes, we shall opt for considering the best choice of the RCP 8.5 pathway in our vulnerability assessment.

8.2 Exposure Database Development

Data Sources: The key data sources used for developing the exposure database for Cuttack city include:

Table 8-3: Data source for exposure data development

Data type	Vintage	Source	Additional information
Ward boundary	2016	CMC	Available in the form of hard copy map which was geo-referenced and boundary and ward information captured
Demography	2011 and projected to 2017	Census of India	Annual growth rate calculated and applied to estimate the current figures
Building (Residential, commercial, industrial)	2011 and projected to 2017	Census of India	Annual growth rate calculated and applied to estimate the current figures
Slum population	2016	CMC	Slum department of CMC has carried out 100% survey of slums of the city
Critical facilities (hospital, schools, fire station)	2011 census data, Bhubaneswar – Cuttack master plan	Census and IIT Kharagpur	Data developed by IIT Kharagpur for the master plan preparation of Bhubaneswar – Cuttack development area
Infrastructure (roads, railway, bridges, inland water bodies	Bhubaneswar – Cuttack master plan	IIT Kharagpur	Data developed by IIT Kharagpur for the master plan preparation of Bhubaneswar – Cuttack development area
Archeological monuments	2011	SOI	SOI maps and further validated with CMC
Land use information, location names	2014 updated using lasted satellite imagery	Cuttack Development Authority	Data developed by IIT Kharagpur for the master plan preparation of Bhubaneswar – Cuttack development area
Cost of replacement for all assets	2017	Various government department of Cuttack and Odisha and expert opinion	Unit cost of construct at current price considered. Mainly used government fixed price

Methodology: The team quantified exposure using the "bottom-up” approach. This includes classifying the different types of houses and infrastructure elements into different categories, estimating their count under each category, combining building counts with per unit built-up floor area in case of buildings or other infrastructure characteristics, and applying per unit costing information relevant to the category. The output of exposure is the total monetary value by asset category. The overall process of developing the exposure database is illustrated in Figure 8-9.

One of the important aspects of exposure data development was to categorize the exposure elements into ‘aggregate’ or ‘site specific’, to analyze the impact of hazards. Aggregate data are those where area and count are summed up at a suitable administrative unit level (for instance at Municipal Ward-level), while the site-specific data are represented by geographic locations (coordinates). A general rule for categorizing data as aggregated or site specific is based on the level at which the location information is available.

The first step of developing exposure database involved collection of data from concerned agencies. In the present study, demographic data was collected from the Census of India and field survey conducted by the project team, while various site-specific data was collected from CMC. During data processing, the tabular and GIS data collected were processed into usable format for the defined exposure elements and brought at the ward level with required attribute information associated with them. The processed data was then analyzed for data gaps and the team identified alternate data sources to fill these gaps.

In the next step, the spatial location of the site-specific exposure data was validated using higher resolution satellite images/ Google Earth. For example, the spatial distribution of houses in this study was determined by using this method. To get an idea of construction practices (construction materials, structural types, architecture, and unit costs) for residential, commercial, industrial buildings, as well as for religious and infrastructural facilities such as roads, bridges, etc., the team undertook sample surveys. During these surveys, inputs from various government and non-government agencies were collected and existing information was validated through personal interviews, photographs, and documents.

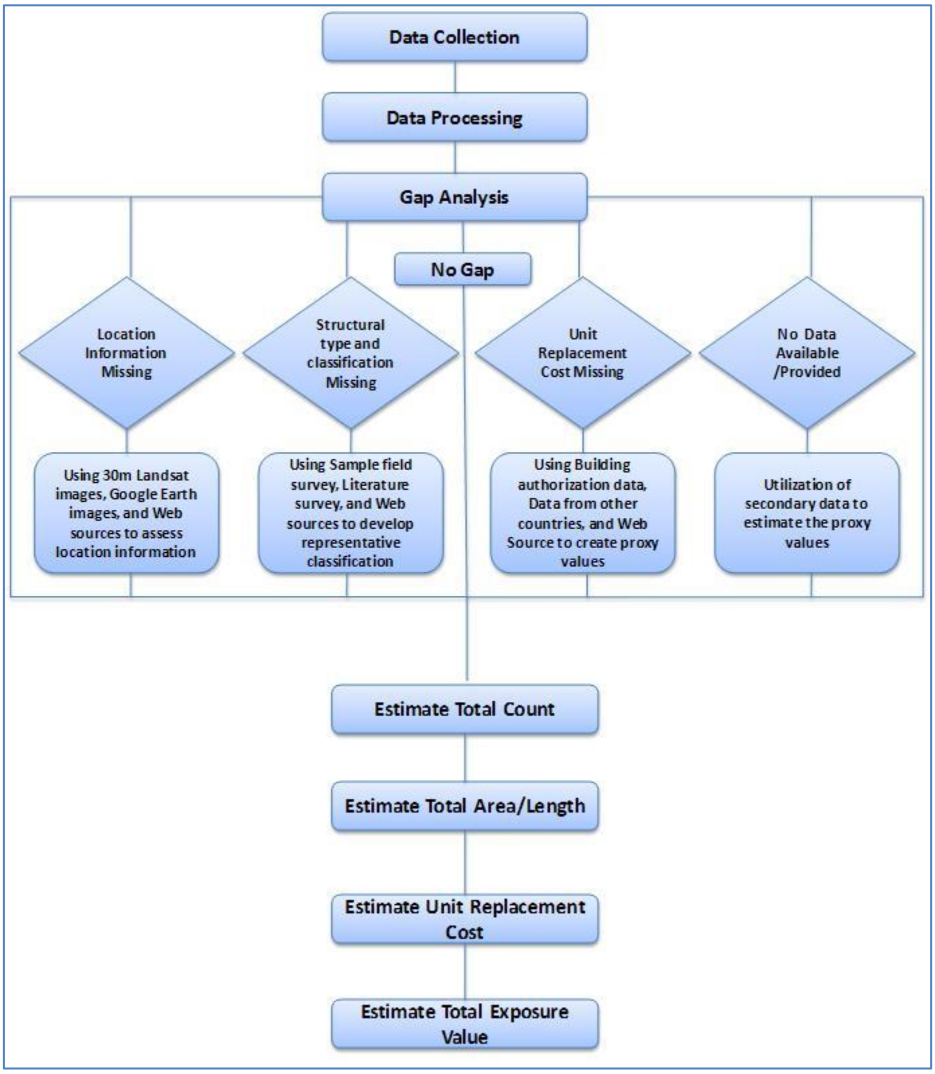

Figure 8-9: Approach to exposure development

The verified and processed data was then used as inputs to the relevant steps (count estimation, area/length estimation, unit cost estimation) from which the final total exposure value was calculated.

8.3 Vulnerability Assessment

Physical vulnerability analysis was carried out using two approaches – based on analyzing the structural vulnerability function to different hazards and by carrying out a sample Rapid Visual Survey (RVS) of different building types in the city.

The structural vulnerability function helps understand the potential and performance of the built environment at different levels of hazard intensity (i.e., flood depth, peak gust, peak ground acceleration/seismic intensity etc.). Various studies such as (US-ASCE, CAPRA, MnhPRA, HAZUS) have conducted vulnerability assessments to analyze the specific characteristics of damage and loss assessment of each identified hazards.

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

For the cyclone hazard, there are three collateral hazards that can take place in isolation or in combination. These are cyclonic wind, flooding due to storm surge, and flooding due to cyclone induced rainfall.

All these hazards, i.e., earthquake, flood, and cyclone have been integrated in the risk assessment section (Component 4 and 5 report- subsequent report).

RVS was conducted among 150 residential buildings and selected critical facilities and the structural details were documented. The critical facilities – schools, hospitals, police stations and fire stations. The sample distribution is provided in Figure 8-10. About 30% of the sample surveyed are masonry structures and about 70% RCC.

Amongst the surveyed buildings:

- 51 (10 are masonry type and 41 are RC frame structure type) are residential;
- 47 (22 are masonry type and 25 are RC frame structure type) are commercial;
- 30 (13 are masonry type and 17 are RC frame structure type) are industrial;
- 6 (RC frame structure type) are residential cum commercial;
- 5 (RC frame structure type) are hospitals;
- 5 (RC frame structure type) are schools;

- 3 (RC frame structure type) are police stations; and
- 3 (RC frame structure type) are fire stations.

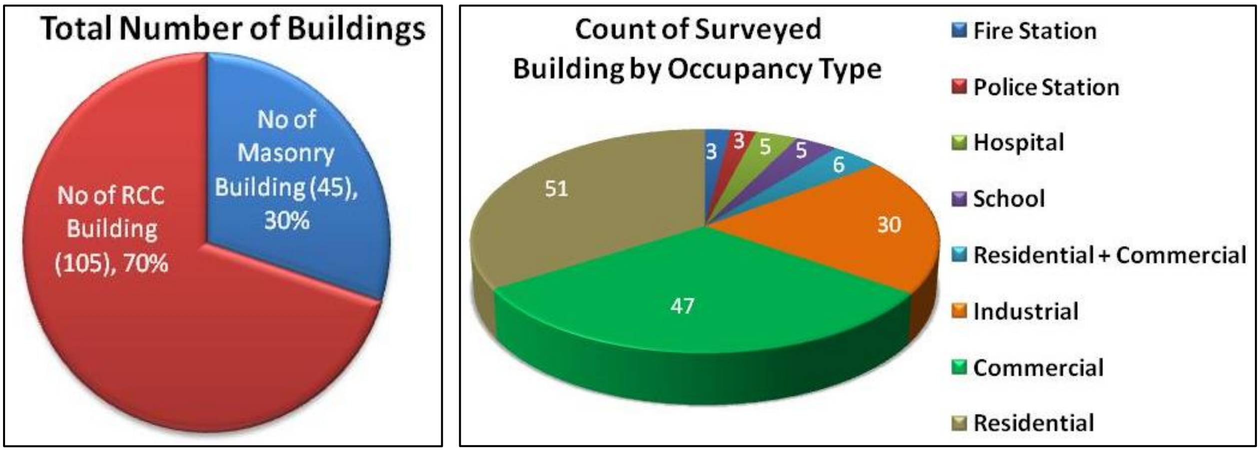

Figure 8-10: Sample distribution by structure type (left) and count of building by occupancy type

The RVS procedure has been developed to identify, create an inventory, and screen buildings that are potentially seismically hazardous. Once identified as potentially hazardous, such buildings should be further evaluated by a design professional experienced in seismic design to determine if, in fact, they are seismically hazardous. The RVS procedure uses a methodology based on a *sidewalk survey* of a building and a data collection form, which the person conducting the survey completes, based on visual observation of the building from its exterior.

Performa customized separately for Masonry and RCC buildings were used for collecting building level information. The sample performa is provided in Annexure 8.9. The evaluation is based on several building parameters such as building height, frame action, pounding effect, structural irregularity, short columns, heavy overhang, soil conditions, falling hazard, apparent building quality, diaphragm action etc. On the basis of above mentioned parameters, performance score of the buildings has been calculated. The formula of the performance score is given as:

$PS= (BS) + \Sigma[(VSM) \times (VS)]$

Where **VSM** represents the Vulnerability Score Modifiers, **VS** represents the Vulnerability Score that is multiplied with **VSM** to obtain the actual modifier to be applied to the Basic Score (Jain et al., 2010).

City/state specific damage assessment reports of various hazards were reviewed to understand the behavior of various structures to different types of hazards.

For social vulnerability analysis, both primary and secondary data are used. Census data are used for all demographic and housing related data at ward level. Where latest census data is not available for instance on female headed households at ward level, we adopted interpolation techniques using district level statistics. Primary data collection through sample survey at household level was carried out to understand the hazard impact, community needs, and community perceptions.

Social vulnerability is partly an outcome of aspects of social setup that influence or shape the susceptibility of various groups of the society to disasters and drive their ability to respond. It is, however, crucial that social vulnerability is not considered as a function of exposure to hazards alone, but also the sensitivity and resilience of the society to prepare, respond and recover from disasters. Social vulnerability is a culmination of economic, demographic, and housing characteristics that influence a community's resilience to the hazards. We adopted a two-pronged approach to assess the social vulnerability of the city:

i. SoVI (Social Vulnerability Index): A scientific approach of analysis of published secondary data based on identified social indicators at ward level.
ii. Community based survey: Analysis of primary data (sample survey) collected through household surveys in selected wards.

The socio economic characteristics and historical hazard events were reviewed to understand the social characteristics of urban communities. Following socio economic variables (Table 8-4) were identified and selected for the vulnerability analysis. Several past studies (Cutter et al., 2003, and S. Kumpulainen 2006) have used similar social indicators that influence social vulnerability for the analysis of social vulnerability.

Table 8-4: Social indicators selected for social vulnerability analysis

Indicators	Description	Normalization
Population	More population means more people exposed to hazard	Population density (person per sq km)
Population age <6 and >60	Children and old people need support in moving out during any emergency. After an event also, this group of population takes more support in getting back to normal life	% population age <6 and > 60 to total population
Female headed household	Women and women headed households struggle more during disaster and recovery due to family responsibilities and lower incomes compared to men	% female headed households to total households
Economic status (based on house type)	More semi-permanent or temporary structures means a higher chance of getting exposed during any disaster	% total kutcha house to total houses
SC and ST population	SC and ST are social and economically disadvantaged group and will struggle more during disaster and recovery	% SC and ST to total population

Note: Most of these indicators are used by several authors elsewhere (Cutter et al, 2003, S.K 2006).

Disaster impacts livelihood of any community and depending on the hazard the impact may linger for a longer duration. In addition to the analysis of social vulnerability, which is a component of the risk factor of the community, it is important to analyze the disaster impact on livelihoods to make the community resilient to disaster. For this, one needs to understand the livelihood profile of the community, key means of livelihood, community behavior to adjust by choosing alternate livelihood etc. The FAO has developed a framework for livelihood assessment (FAO 2009) for responding to the impact of disasters on the livelihood of people. In the present situation, the analysis was carried out within this framework to assess the impact of disasters on the livelihood of the city dwellers.

The selected variables were analyzed to develop the social vulnerability index (SoVI) across the wards. This index provides information on vulnerability distinction of the community thus allowing intervention by way of appropriate mitigation and prevention activities. SoVI will prove valuable for the city administration and state towards planning and decision-making, as it graphically illustrates the geographic variations in social vulnerability by reflecting the uneven capacity of preparedness and response.

The following steps were followed for the SoVI analysis:

- The secondary data on the identified indicators pertaining to the same time-period was collected at ward level and used as input variables to calculate the vulnerability index.
- The variables were normalized as percentages, per capita values, or density functions
- Accuracy of the data sets was verified using descriptive statistics

- Weightage was applied to the social indicators using Analytic Hierarchy Process (AHP) method and cumulative score was derived, which is the SOVI
- The SoVI was mapped using objective classification in ward boundary map illustrating areas of very high, high, medium and low social vulnerability.

Community based survey: Household survey was conducted in selected wards using a structured pre-tested questionnaire. A total of 150 households were selected from 10 wards for the survey. For ward selection, both the hazard history and socio economics of the ward were considered. For the selection of the household, we first analyzed the percentage of house types in the city at ward level and similar percentage composition of pucca, semi kutcha, and kutcha houses were selected. The samples were selected randomly from the identified wards.

The secondary and primary data collected was tabulated and analyzed for understanding community specific needs and issues. The SOVI developed is used to present the social vulnerability distribution across the city and the household survey data was used to analyze the vulnerability aspects related to specific hazards, event history, losses, diseases, and perception of community toward DRR.

For economic vulnerability, indirect methods were adopted as information related to income or other economic indicators are not available at ward level for the city. Ideally, occupation-level income data, aggregated at ward level, can provide a direction to analyze the economic vulnerability of wards to particular hazards. In the absence of such data, we adopted estimated income based on broad livelihood categories and estimated the income loss due to hazards to analyze the economic impact of the hazards.

For environmental vulnerability, the city's changing land use land cover (LULC) was considered as the key factor, particularly increases in built up and the reduction in wetlands.

8.4 Risk Assessment

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

Loss is a function of the damage ratio, which is derived through the damage function (vulnerability curve), translated into currency loss by multiplying the damage ratio by the value at risk.

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

where,

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

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

For structures, the direct losses can be computed using the MDR and structures' economic value (exposure value, discussed in the Exposure part of earlier report).

As discussed in the Report on Component 1, 2, and 3 - hazard section, 5, 10, 25, 50, and 100 years return-period hazard maps are have been developed for flood and cyclonic wind hazard and 475-years for earthquake hazard. Direct losses are calculated for different return period scenario events (5, 10, 25, 50, and 100 years for floods and cyclonic winds, and 475 – years for earthquakes) and for all types of exposure at risk like residential, commercial, industrial buildings, and infrastructure. This analysis has been carried out for each asset class at each location where the treatment of location differs from hazard to hazard and asset class to asset class at ward level and losses are then aggregated at the city level.

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

where:

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

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

Once the losses have been computed for every return-period, two most common types of outputs are generated: AAL and LEC Curves.

AAL is calculated using the following equation:

$$AAL(j) = \sum_{i=0}^{n} L(i,j) * R(i) \qquad \textbf{Equation 3}$$

where:

L(i,j) = Loss for event 'I' and exposure type 'j'

R(i) = Rate of occurrence of event 'i'

LEC curve is the second output that is generated. LEC is a graphical representation of the probability that a certain level of loss is exceeded in a given time period. This is expressed in terms of monetary values for different types of exposure. The probability of loss is obtained from the rate of occurrence and is calculated as shown below.

$$EP(i) = e\ power(\textstyle\sum_{0}^{i} Ri) \qquad \textbf{Equation 4}$$

where, R is the rate of occurrence of an event

Using the LEC, losses have been estimated for key return periods for all the hazards.

Next, GIS based risk maps showing AAL and losses for various key return periods have been generated showing the areas likely to get affected at the ward/city level.

In the present context, the direct loss is the hazard-induced losses in terms of financial losses for various structures based on their valuations. The spatial distribution of the modeled risk outputs are portrayed in the form of maps showing the hazard, exposure, and risk characteristics. The temporal characteristics of the modeled risk outputs are depicted in the form of LECs.

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

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

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

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

Aggregated Exposure: Aggregated exposure at ward level has been applied for cyclonic winds and earthquake. The losses have been estimated only on the area of the built-up cluster that is in a cyclonic wind speed grid or for certain Peak Ground Acceleration (PGA) grid.

Site specific Exposure: Site-specific exposure features ae location-type exposures, such as bridges, roads, railway lines, electric transmission lines, pipelines, etc. Since, such line type exposure elements are often spread over a long area, a single hazard value cannot be used to estimate the losses to them. Since a line type exposure element is made of a set of smaller segments, the loss is estimated at the centroid of every segment. The losses of all the segments are summed up to estimate the loss to the line exposure element.

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

$$L(i, j, k) = \sum_{l=0}^{m} MDR(j,i,h) * Value\_At\_Risk(j,k,l) \qquad \textbf{Equation 5}$$

where:

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

MDR(j,i,h) = Mean Damage Ratio for exposure type ‘j’ at a hazard intensity ‘h’ for event i

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

AAL, at any location, is calculated using the following equation:

$$\mathbf{AAL(j,\ k)} = \sum_{i=0}^{n} L(i, j, k) * R(i) \qquad \textbf{Equation 6}$$

where:

AAL(j, k) = AAL for exposure type ‘j’ and line element ‘k’

L(i,j,k) = Loss for event ‘i’ and exposure type ‘j’ and line element ‘k’

R(i) = Rate of occurrence of event ‘i’

The following sections illustrate the estimated losses and discuss them. The losses are presented as tables and maps depicting the losses in different ways to make the underlying risk easier to understand.

8.5 Annexure 2: Cyclone and Flood Hazard Data and Maps

Cyclone Hazard Data and Maps

Table 8-5: List of cyclone events during (1877-2016) used for analysis

Sl. No.	Type of Disturbance	Day	Month	Year	Maximum wind speed in km/h
1	Very Severe Cyclonic Storm	15	5	1877	118
2	Deep Depression	3	8	1878	56
3	Deep Depression	13	9	1878	56
4	Deep Depression	22	9	1879	56
5	Deep Depression	25	6	1880	56
6	Deep Depression	21	9	1880	56
7	Deep Depression	2	7	1881	56
8	Deep Depression	2	8	1881	56
9	Cyclonic Storm	11	7	1882	83
10	Cyclonic Storm	6	9	1882	83
11	Cyclonic Storm	12	10	1882	83
12	Cyclonic Storm	12	7	1883	83
13	Deep Depression	19	6	1884	56
14	Deep Depression	15	7	1884	56
15	Cyclonic Storm	24	10	1884	83
16	Deep Depression	14	7	1885	56
17	Cyclonic Storm	19	9	1885	83
18	Cyclonic Storm	12	8	1886	83
19	Very Severe Cyclonic Storm	13	9	1888	118
20	Deep Depression	18	6	1890	56
21	Deep Depression	1	7	1890	56
22	Deep Depression	10	10	1890	56
23	Very Severe Cyclonic Storm	1	11	1891	118
24	Cyclonic Storm	7	9	1892	83
25	Cyclonic Storm	21	9	1893	83
26	Cyclonic Storm	11	7	1894	83
27	Deep Depression	27	9	1894	56
28	Cyclonic Storm	11	9	1898	83
29	Cyclonic Storm	9	10	1898	83
30	Cyclonic Storm	8	8	1899	83
31	Deep Depression	27	8	1899	56
32	Cyclonic Storm	12	10	1899	83
33	Cyclonic Storm	11	6	1900	83
34	Cyclonic Storm	29	7	1900	83
35	Deep Depression	9	8	1900	56
36	Deep Depression	4	10	1900	56
37	Cyclonic Storm	12	7	1903	83
38	Deep Depression	1	8	1903	56
39	Cyclonic Storm	5	10	1903	63
40	Cyclonic Storm	30	6	1905	83

Sl. No.	Type of Disturbance	Day	Month	Year	Maximum wind speed in km/h
41	Deep Depression	7	9	1905	56
42	Cyclonic Storm	21	7	1906	83
43	Deep Depression	27	8	1906	56
44	Deep Depression	1	8	1908	56
45	Cyclonic Storm	28	8	1908	83
46	Cyclonic Storm	9	6	1911	83
47	Deep Depression	28	8	1911	56
48	Cyclonic Storm	27	7	1912	83
49	Cyclonic Storm	1	8	1912	83
50	Very Severe Cyclonic Storm	28	10	1912	118
51	Cyclonic Storm	16	7	1913	63
52	Cyclonic Storm	30	8	1913	83
53	Deep Depression	13	8	1916	56
54	Very Severe Cyclonic Storm	1	5	1917	118
55	Deep Depression	5	9	1917	56
56	Deep Depression	1	10	1917	56
57	Deep Depression	28	7	1918	56
58	Deep Depression	1	7	1919	56
59	Deep Depression	24	8	1919	56
60	Deep Depression	20	6	1920	56
61	Deep Depression	21	7	1920	56
62	Depression	15	7	1920	46
63	Deep Depression	25	8	1920	56
64	Deep Depression	2	9	1921	56
65	Deep Depression	8	9	1922	56
66	Deep Depression	19	7	1923	56
67	Very Severe Cyclonic Storm	10	11	1923	118
68	Deep Depression	25	8	1924	56
69	Deep Depression	9	10	1924	56
70	Deep Depression	30	8	1925	56
71	Deep Depression	5	8	1926	56
72	Cyclonic Storm	14	9	1926	83
73	Cyclonic Storm	16	6	1927	83
74	Deep Depression	11	8	1927	56
75	Cyclonic Storm	1	10	1928	83
76	Deep Depression	11	7	1929	56
77	Cyclonic Storm	23	8	1929	63
78	Cyclonic Storm	28	6	1930	83
79	Deep Depression	30	8	1931	56
80	Deep Depression	24	7	1932	56
81	Deep Depression	2	9	1932	56
82	Deep Depression	8	8	1933	56
83	Deep Depression	12	9	1933	56
84	Deep Depression	15	8	1934	56

Sl. No.	Type of Disturbance	Day	Month	Year	Maximum wind speed in km/h
85	Deep Depression	7	9	1935	56
86	Deep Depression	5	9	1936	56
87	Very Severe Cyclonic Storm	29	9	1936	118
88	Deep Depression	11	7	1937	56
89	Deep Depression	3	9	1937	56
90	Deep Depression	24	6	1940	56
91	Deep Depression	20	8	1940	56
92	Deep Depression	28	6	1941	56
93	Deep Depression	29	8	1942	56
94	Deep Depression	26	9	1942	56
95	Cyclonic Storm	24	7	1943	63
96	Deep Depression	9	7	1944	56
97	Cyclonic Storm	28	7	1944	63
98	Cyclonic Storm	18	8	1944	83
99	Depression	28	9	1945	46
100	Depression	16	8	1946	46
101	Cyclonic Storm	11	8	1948	65
102	Depression	12	9	1949	46
103	Cyclonic Storm	23	7	1951	65
104	Depression	6	8	1954	46
105	Depression	1	9	1954	46
106	Cyclonic Storm	29	9	1955	65
107	Depression	20	9	1955	46
108	Cyclonic Storm	18	8	1957	65
109	Depression	28	8	1958	46
110	Cyclonic Storm	27	6	1959	65
111	Depression	3	7	1959	46
112	Depression	29	6	1960	46
113	Depression	4	8	1964	46
114	Depression	16	7	1966	46
115	Depression	2	9	1966	46
116	Very Severe Cyclonic Storm	30	12	1966	120
117	Depression	30	7	1967	46
118	Very Severe Cyclonic Storm	7	10	1967	120
119	Cyclonic Storm	9	9	1968	65
120	Depression	6	7	1973	46
121	Severe Cyclonic Storm	3	11	1973	111
122	Cyclonic Storm	26	9	1974	65
123	Depression	18	6	1975	46
124	Depression	25	6	1975	46
125	Depression	9	9	1975	46
126	Depression	1	8	1976	46
127	Severe Cyclonic Storm	30	5	1982	102
128	Depression	20	8	1990	50

Sl. No.	Type of Disturbance	Day	Month	Year	Maximum wind speed in km/h
129	Deep Depression	17	6	1992	56
130	Deep Depression	26	7	1992	56
131	Super Cyclonic Storm	25	10	1999	260
132	Depression	12	6	2001	46
133	Deep Depression	11	6	2004	56
134	Depression	12	9	2005	46
135	Deep Depression	2	7	2006	56
136	Deep Depression	2	8	2006	56
137	Depression	16	8	2006	46
138	Depression	29	8	2006	46
139	Deep Depression	28	6	2007	56
140	Deep Depression	5	8	2007	56
141	Depression	9	8	2008	46
142	Depression	7	10	2010	46

Return Period Wind Hazard Maps with no Climate Change Impact

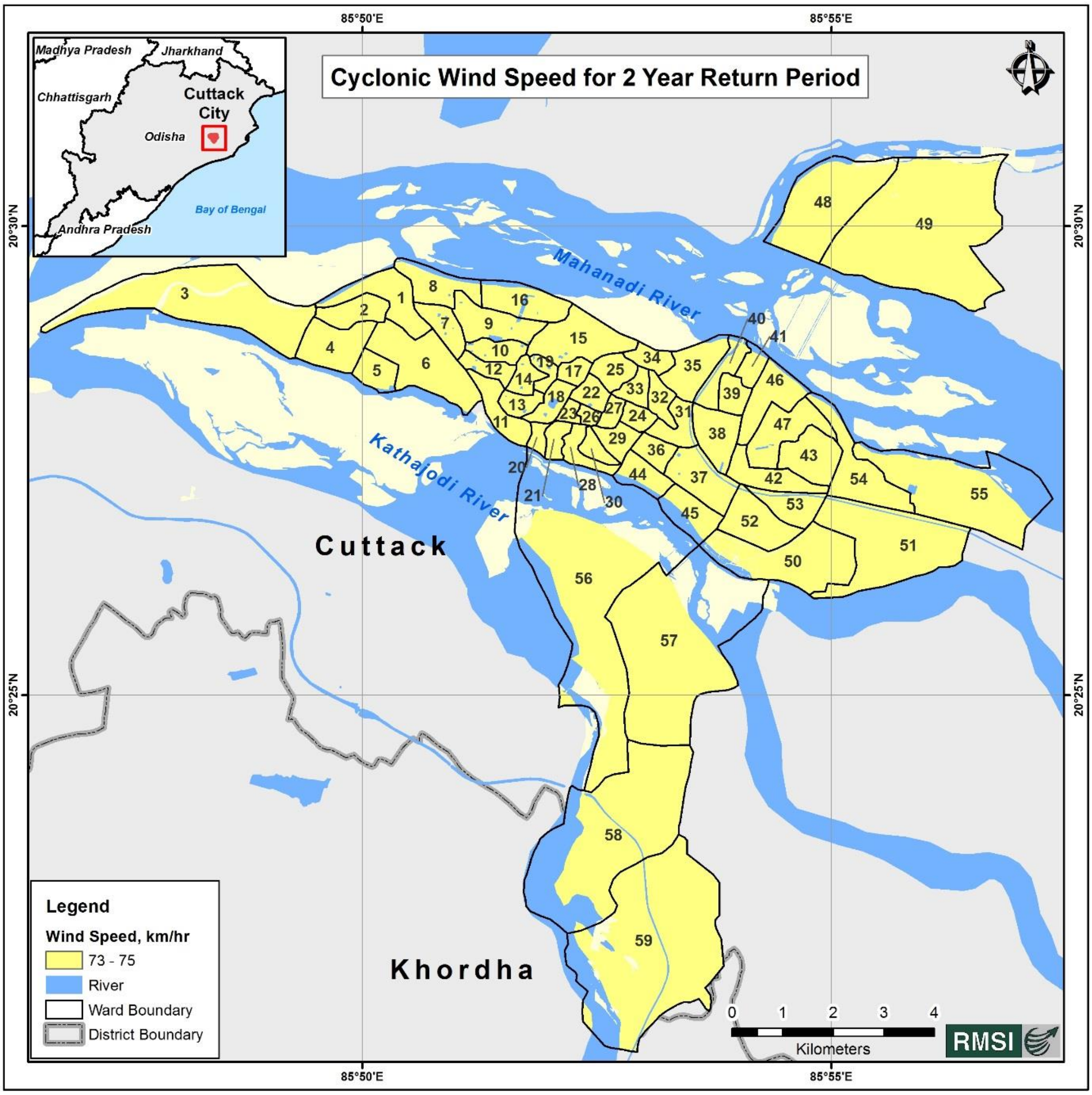

Figure 8-11: Wind hazard map for 2-year return period without climate change impact

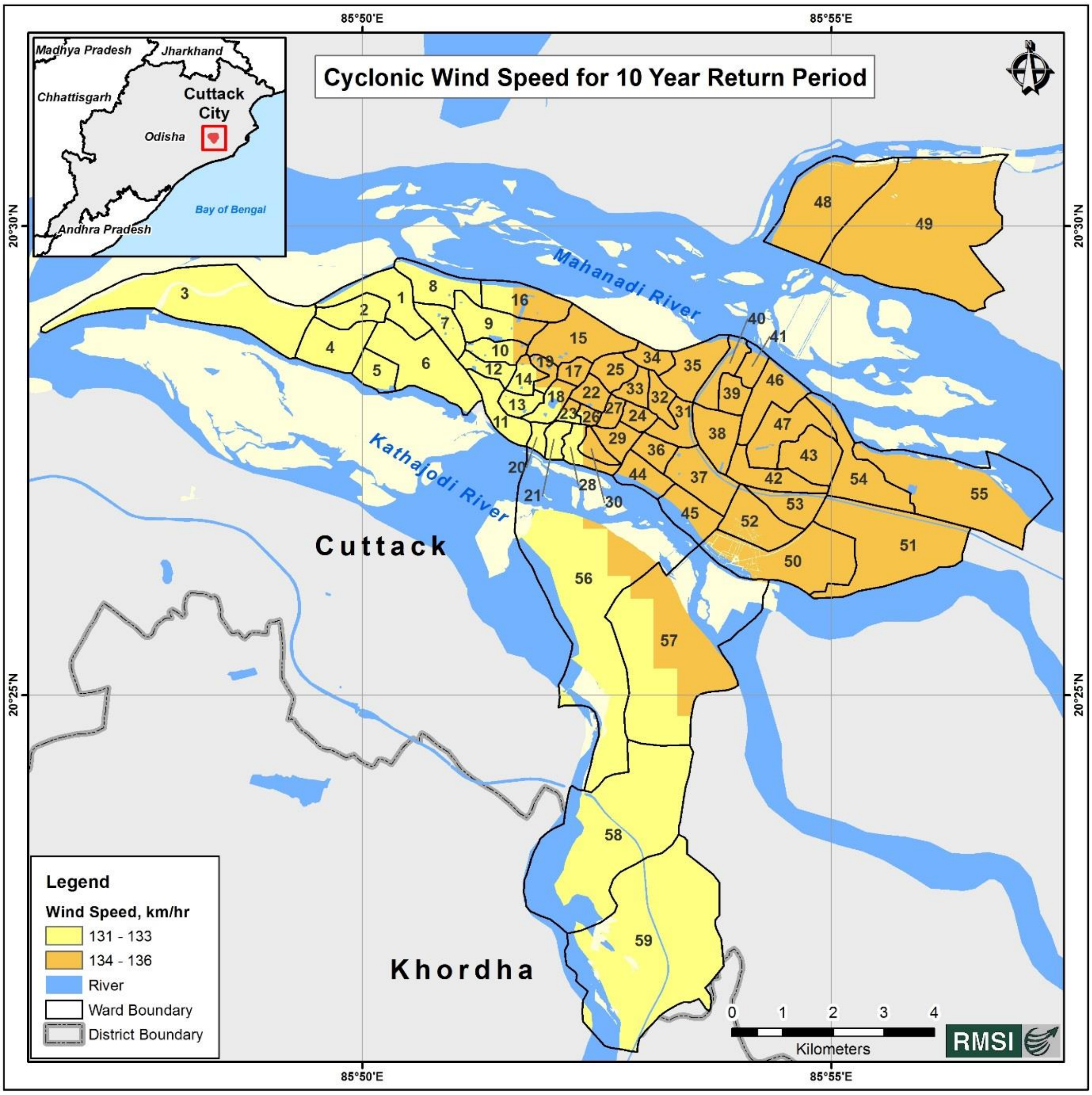

Figure 8-12: Wind hazard map for 10-year return period without climate change impact

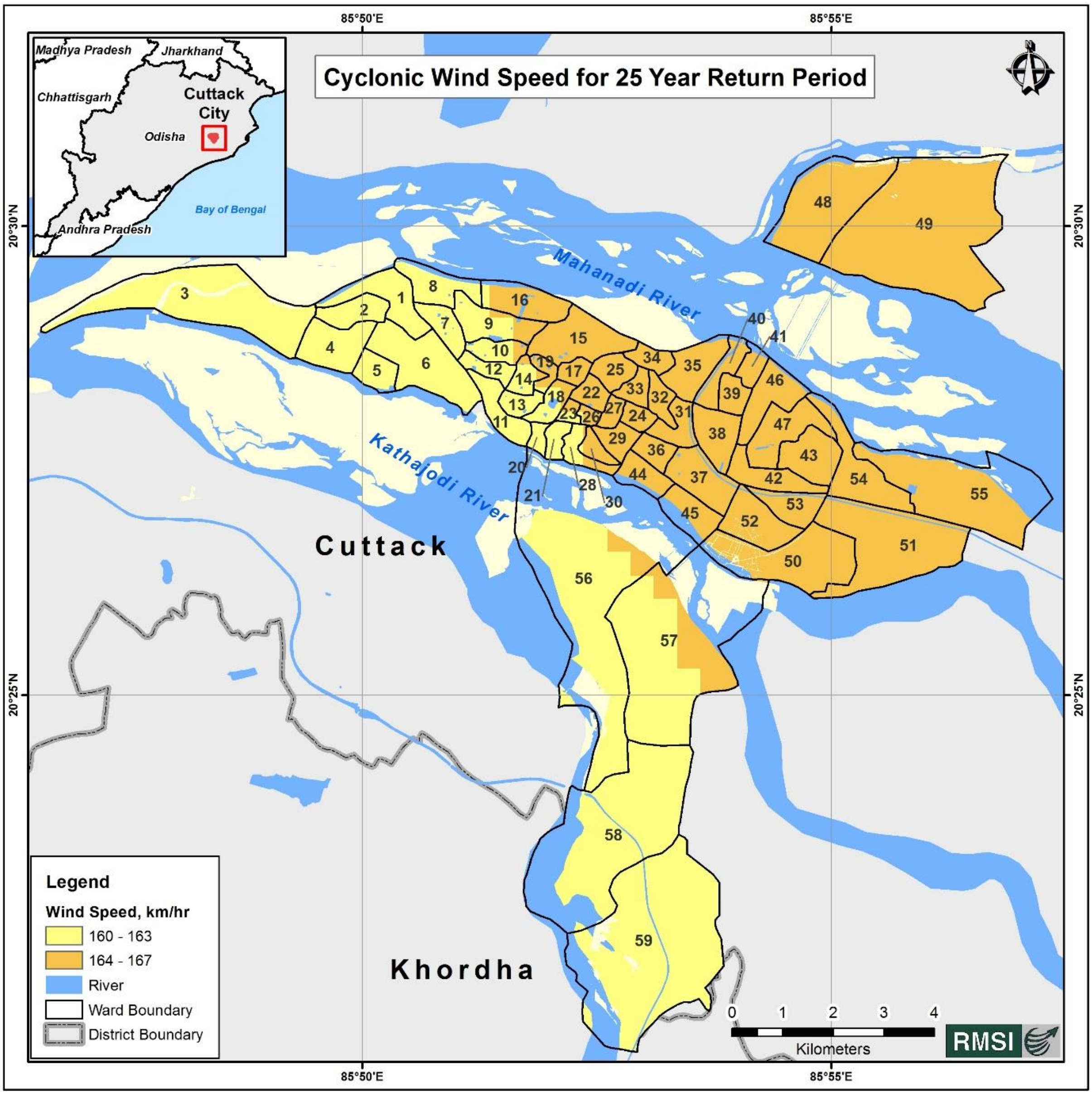

Figure 8-13: Wind hazard map for 25-year return period without climate change impact

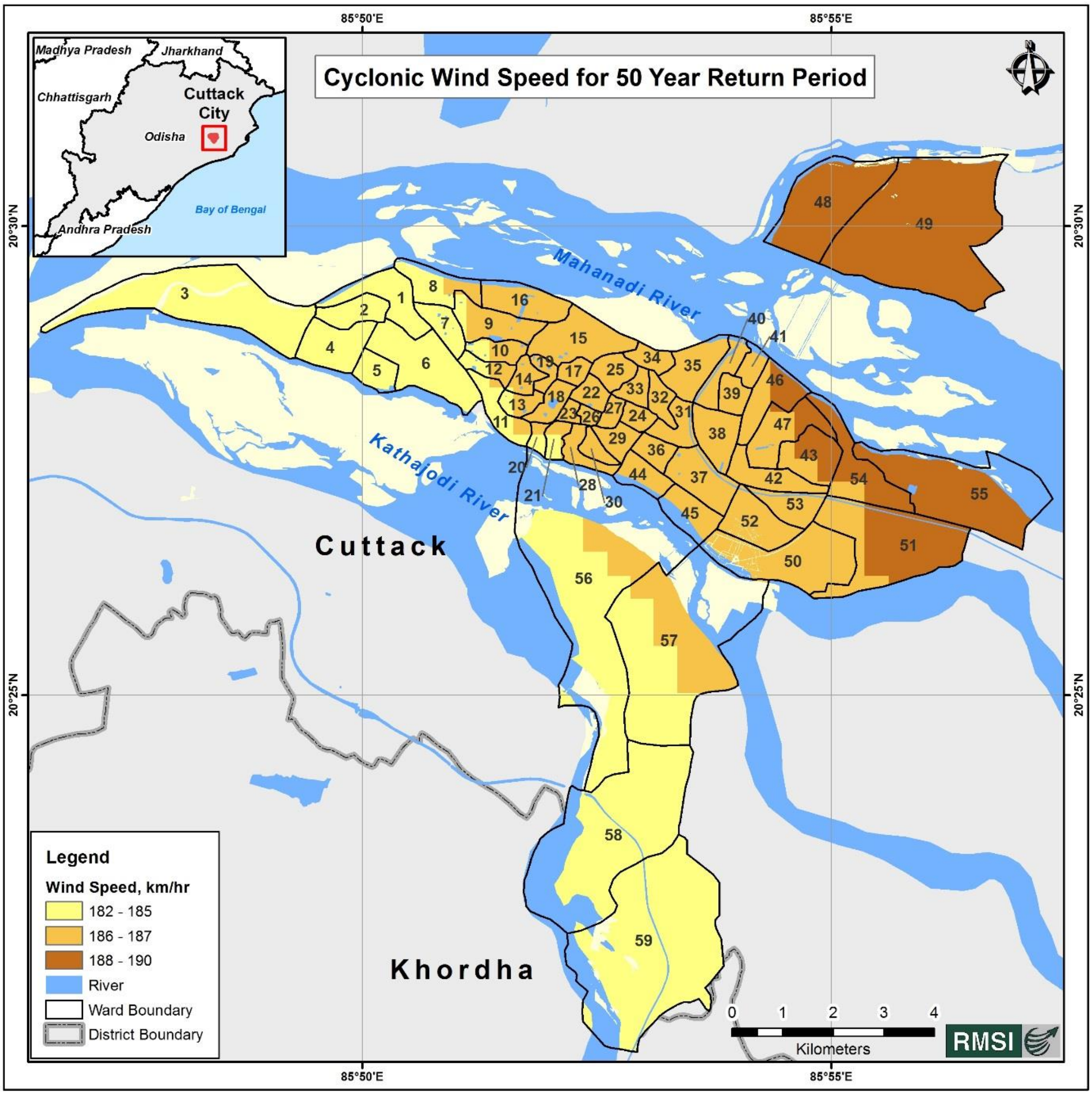

Figure 8-14: Wind hazard map for 50-year return period without climate change impact

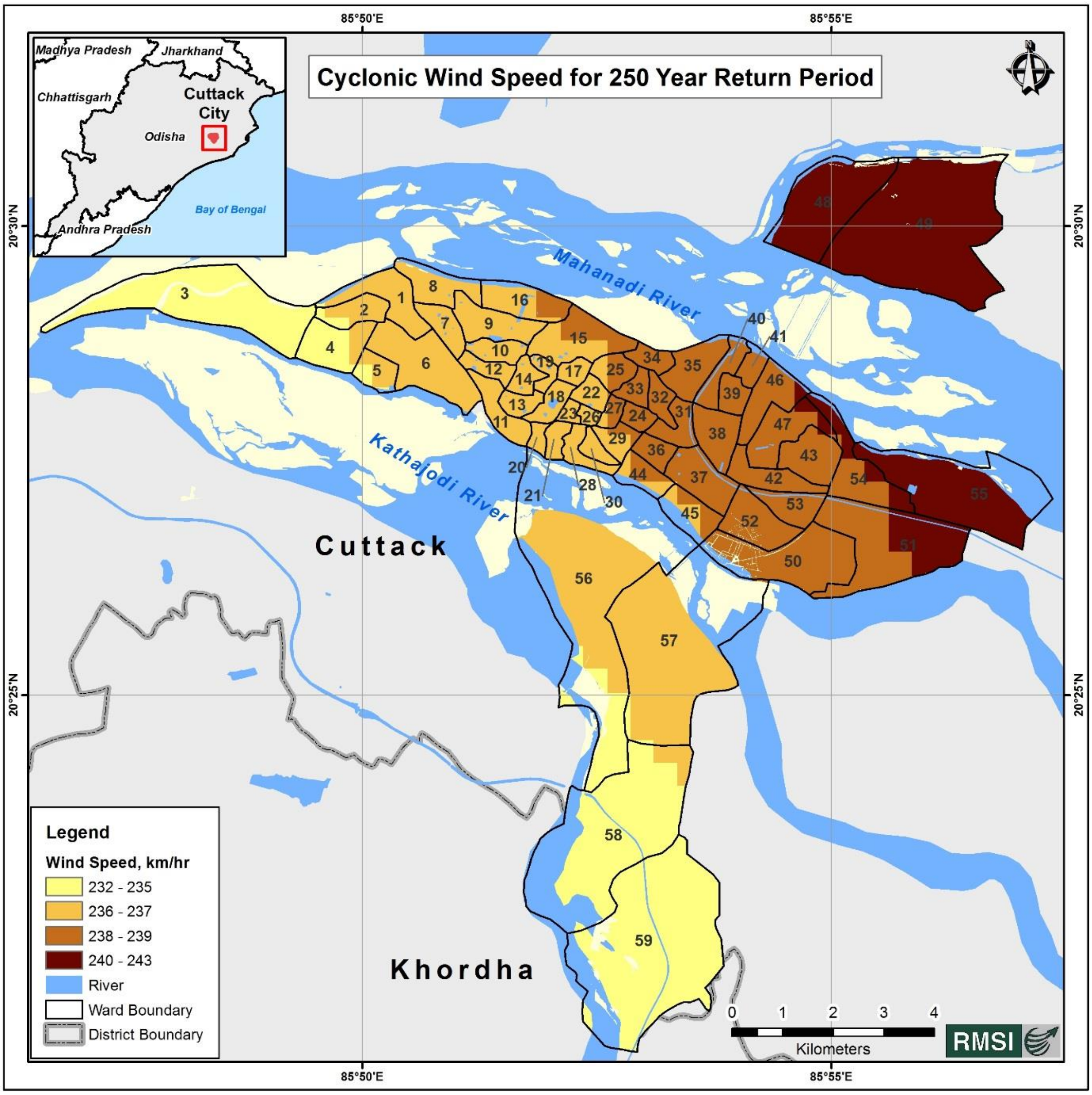

Figure 8-15: Wind hazard map for 250-year return period without climate change impact

Figure 8-16: Wind hazard map for 500-year return period without climate change impact

8.5.1 RETURN PERIOD WIND HAZARD MAPS WITH CLIMATE CHANGE IMPACT OF 7%

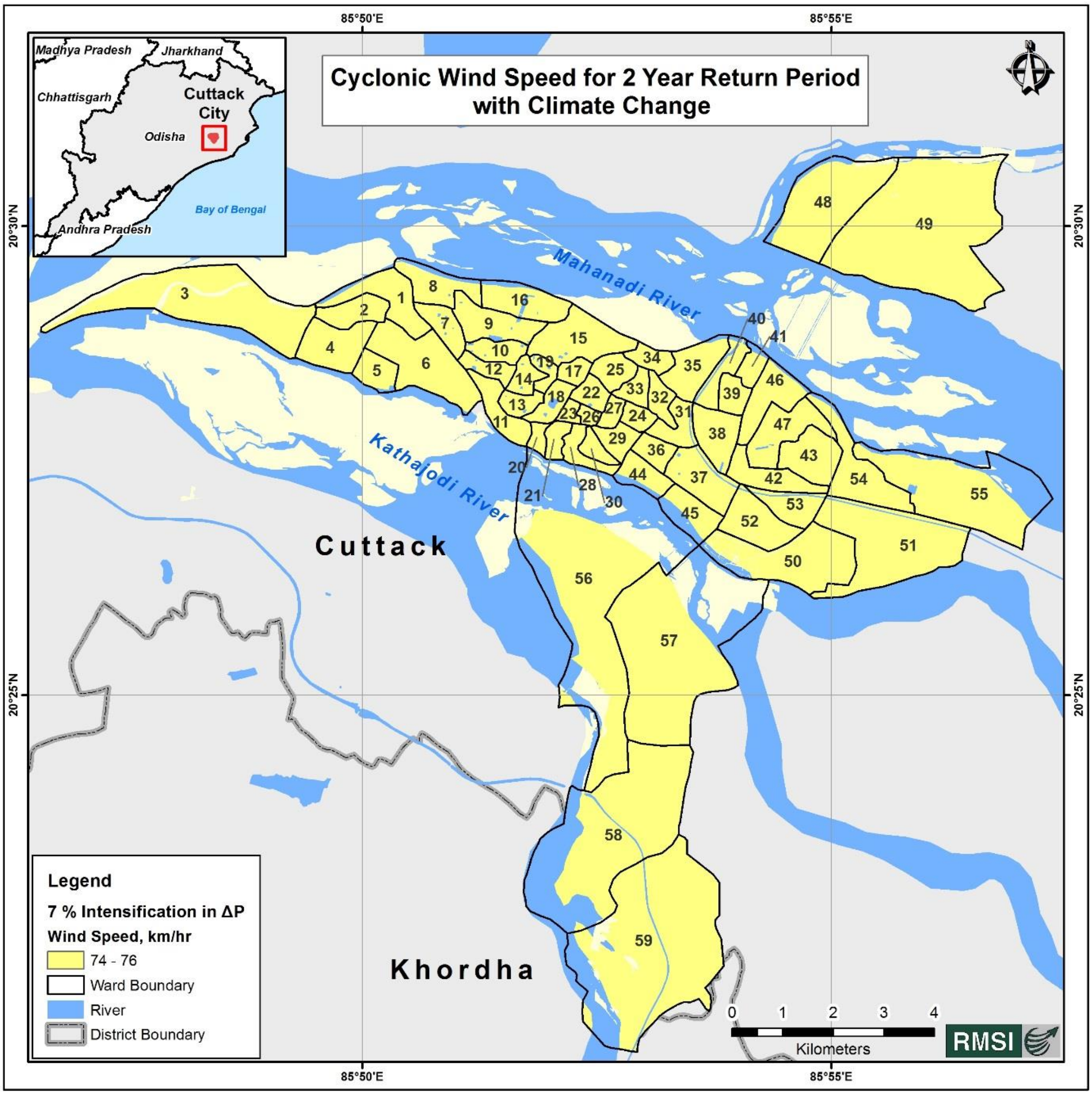

Figure 8-17: Wind hazard map for 2-year return period with climate change impact of 7%

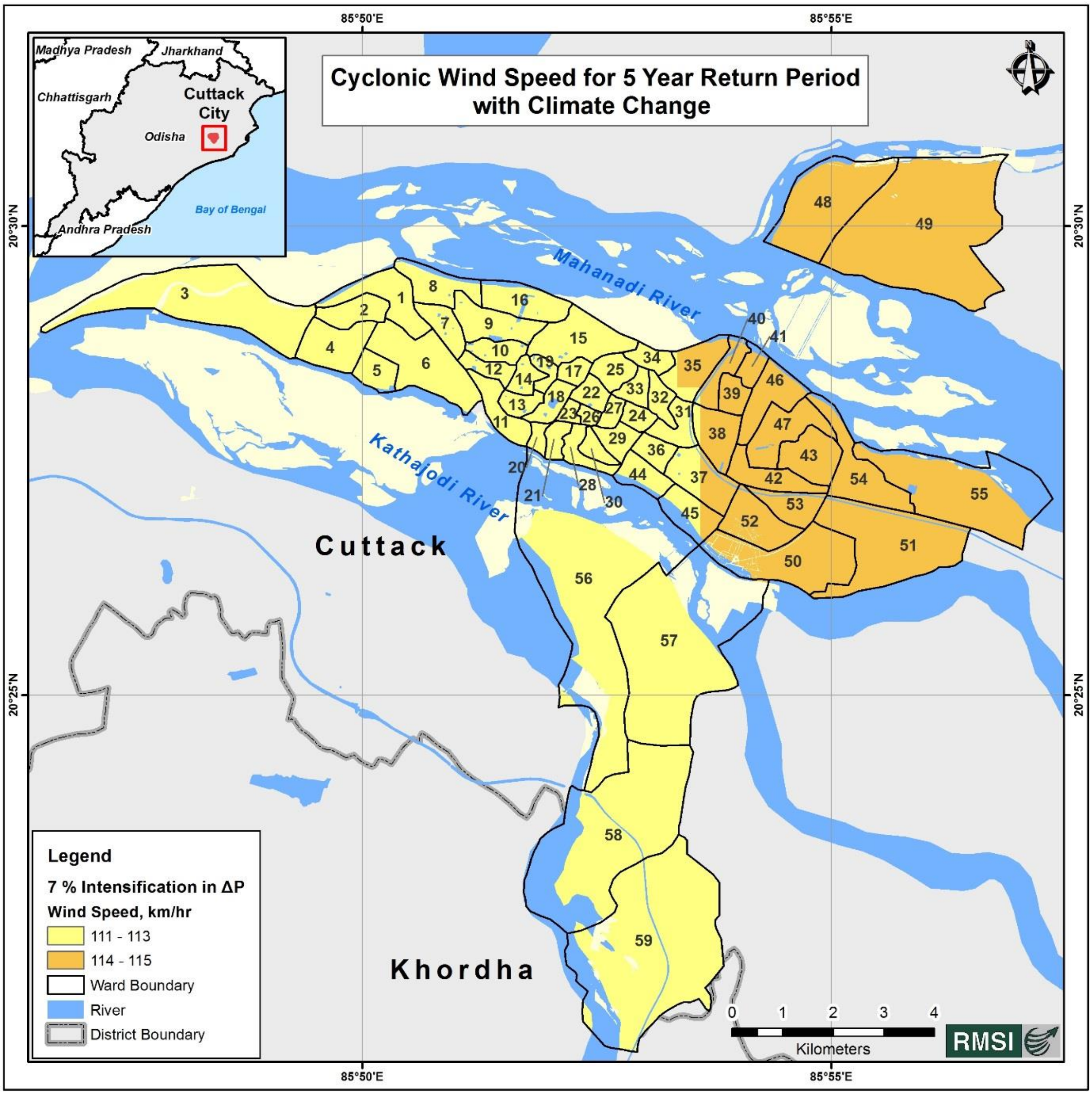

Figure 8-18: Wind hazard map for 5-year return period with climate change impact of 7%

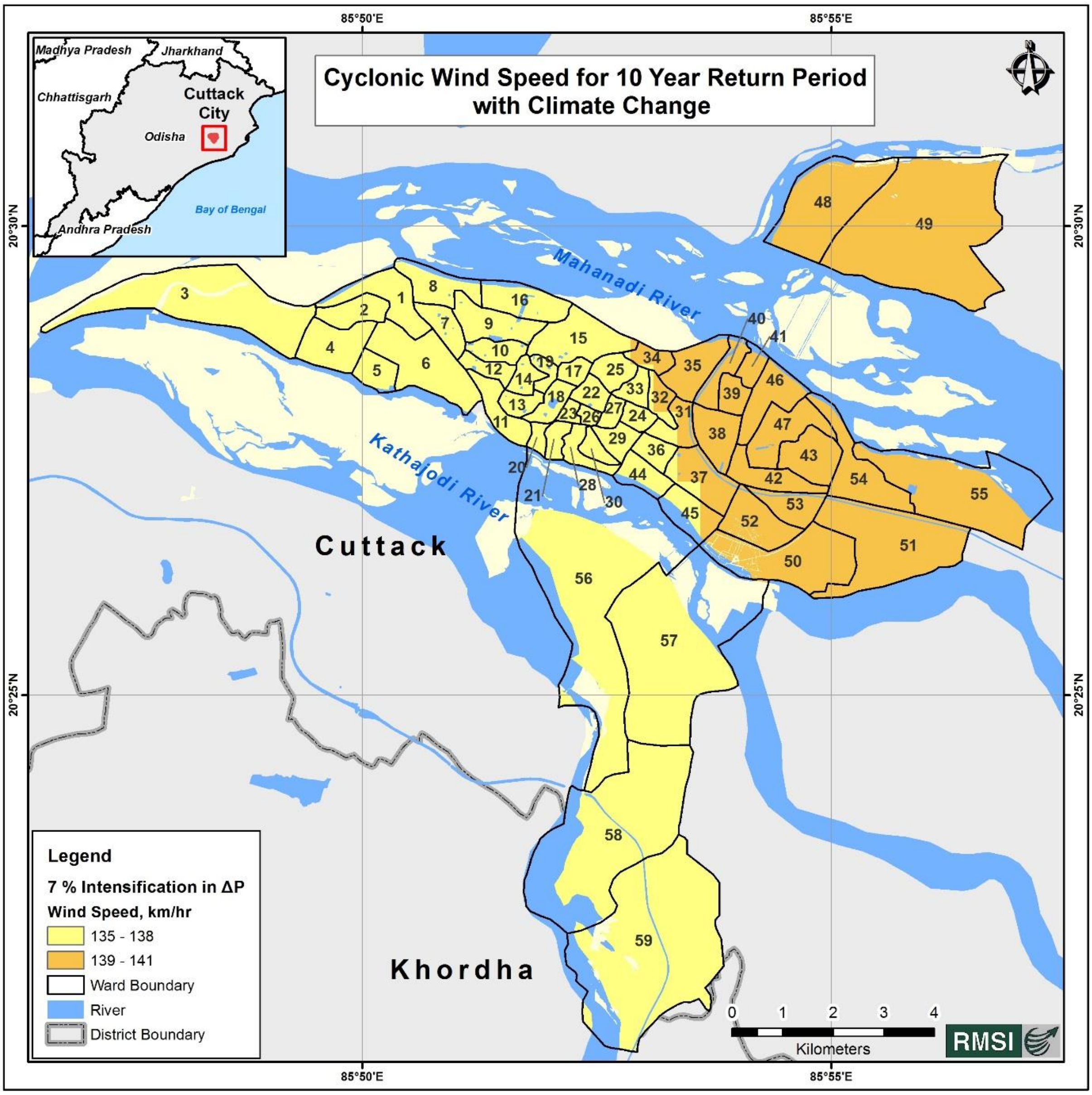

Figure 8-19: Wind hazard map for 10-year return period with climate change impact of 7%

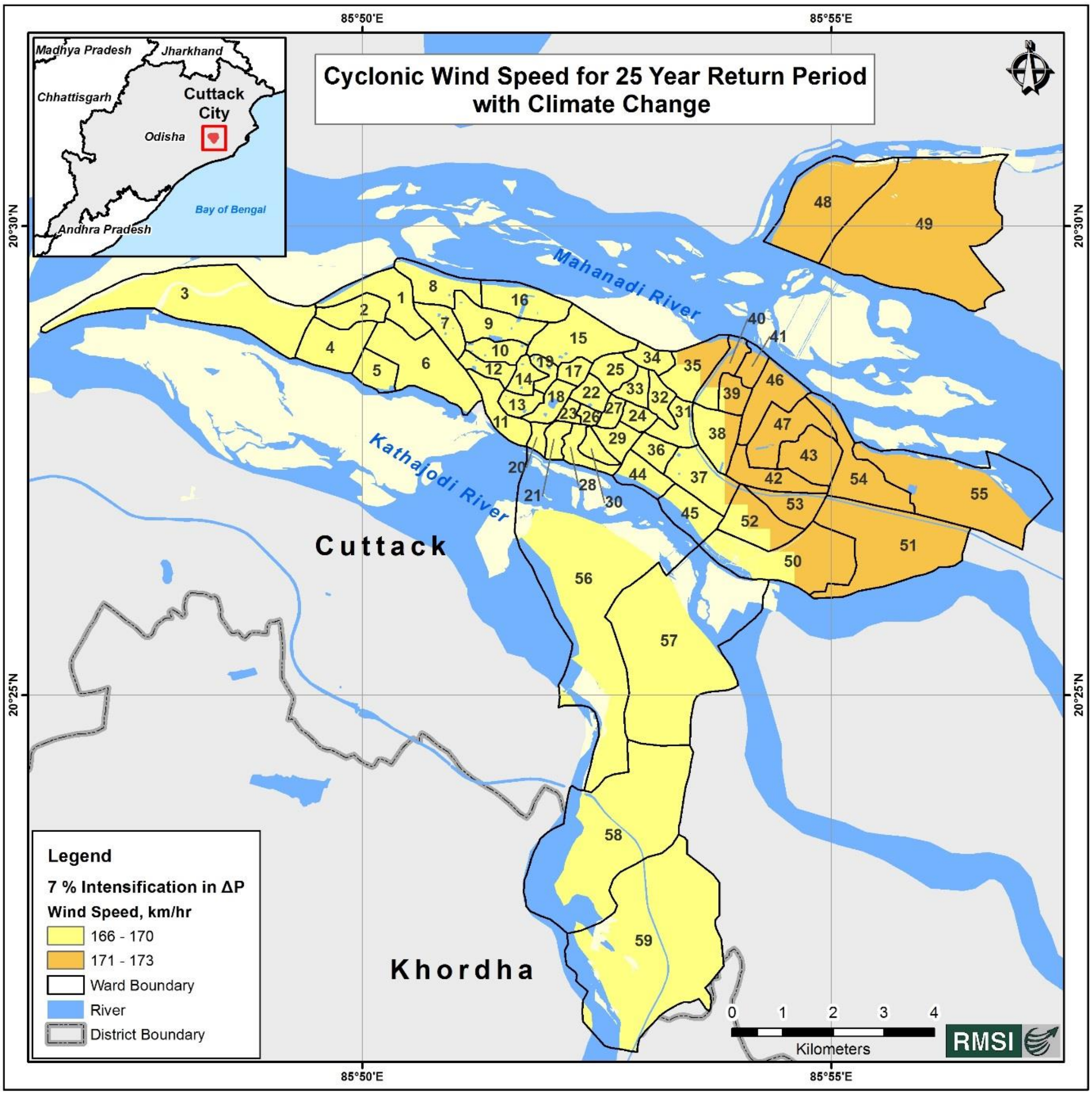

Figure 8-20: Wind hazard map for 25-year return period with climate change impact of 7%

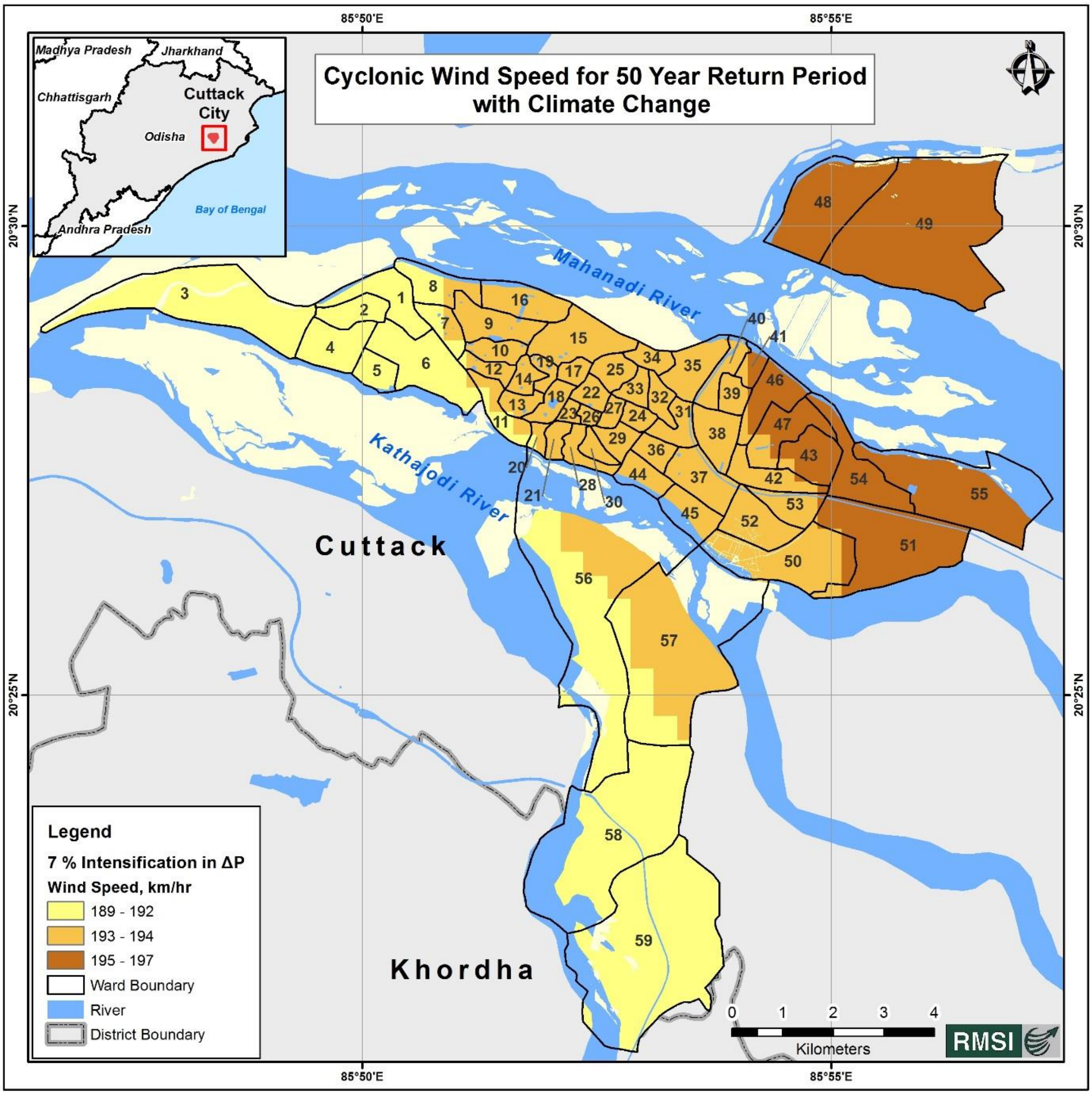

Figure 8-21: Wind hazard map for 50-year return period with climate change impact of 7%

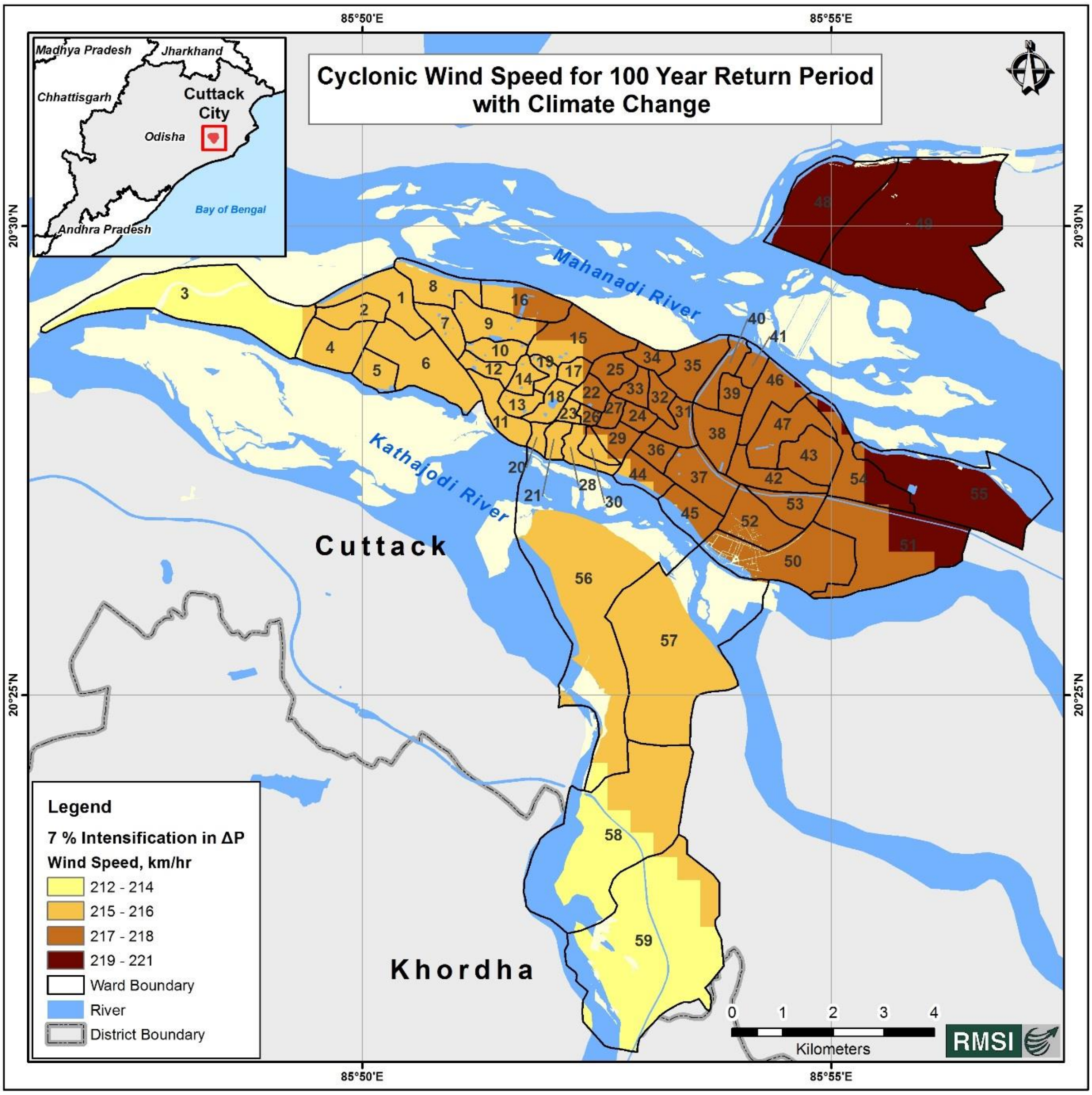

Figure 8-22: Wind hazard map for 100-year return period with climate change impact of 7%

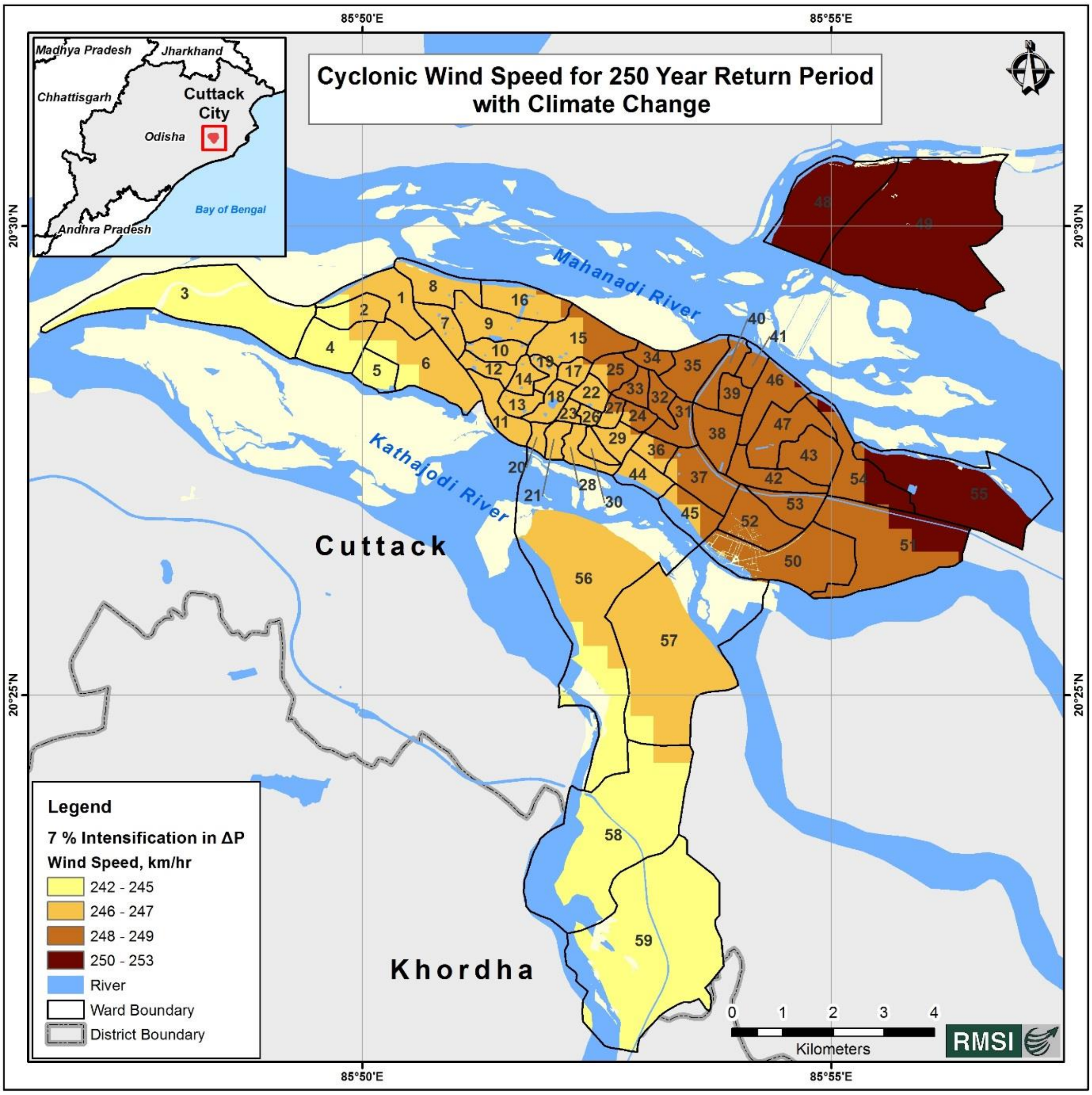

Figure 8-23: Wind hazard map for 250-year return period with climate change impact of 7%

8.5.2 RETURN PERIOD WIND HAZARD MAPS WITH CLIMATE CHANGE IMPACT OF 11%

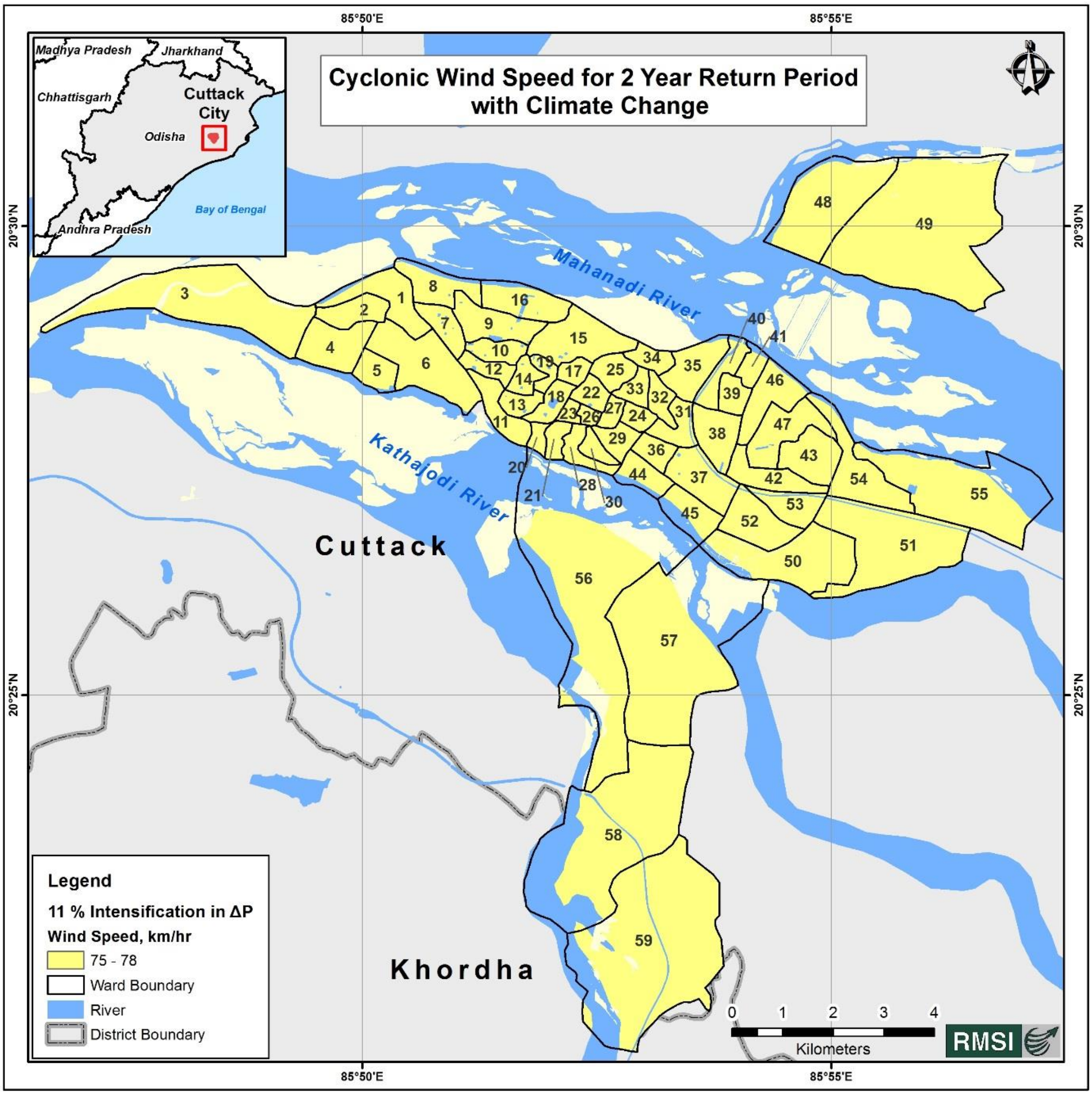

Figure 8-24: Wind hazard map for 2-year return period with climate change impact of 11%

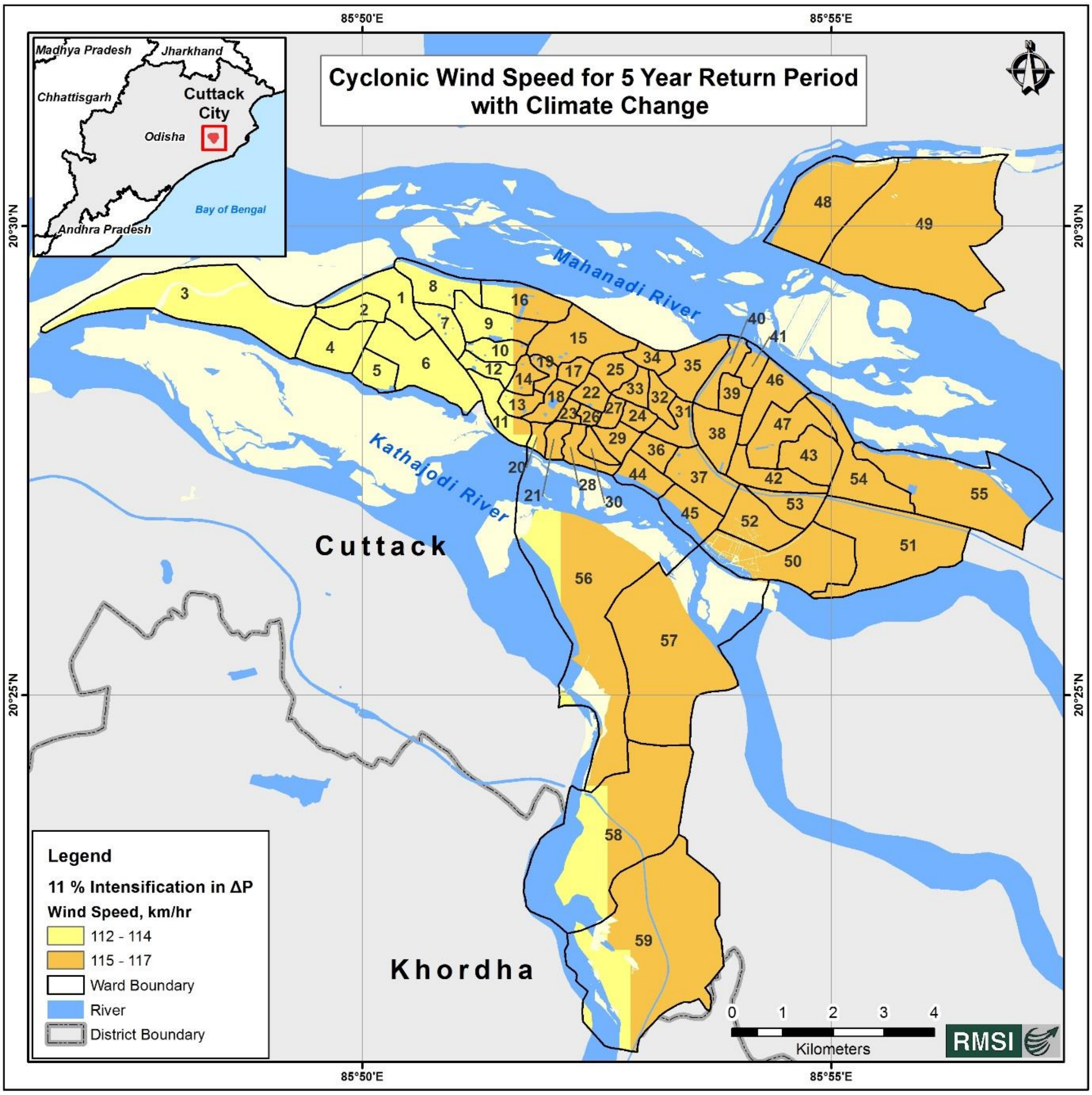

Figure 8-25: Wind hazard map for 5-year return period with climate change impact of 11%

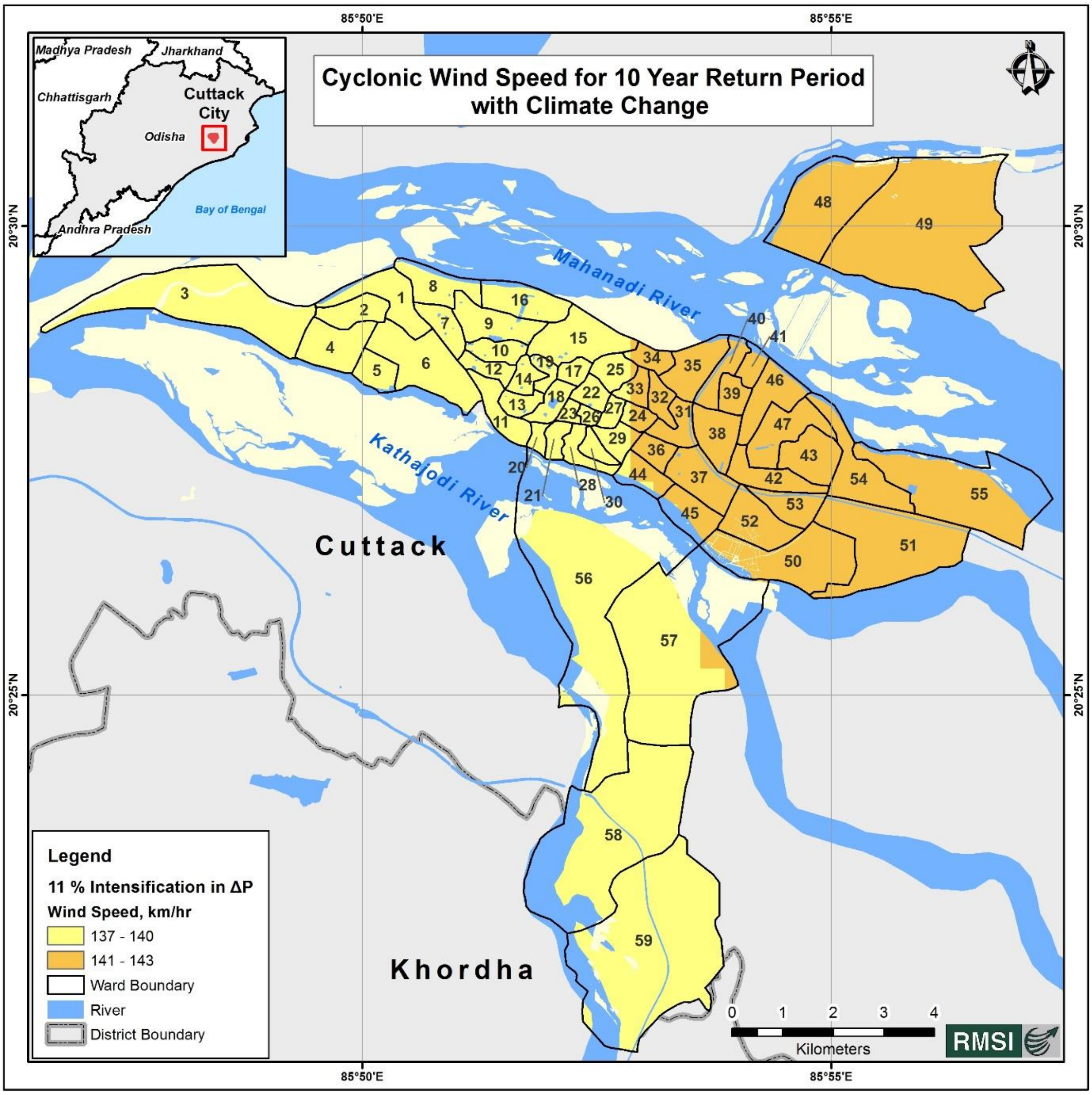

Figure 8-26: Wind hazard map for 10-year return period with climate change impact of 11%

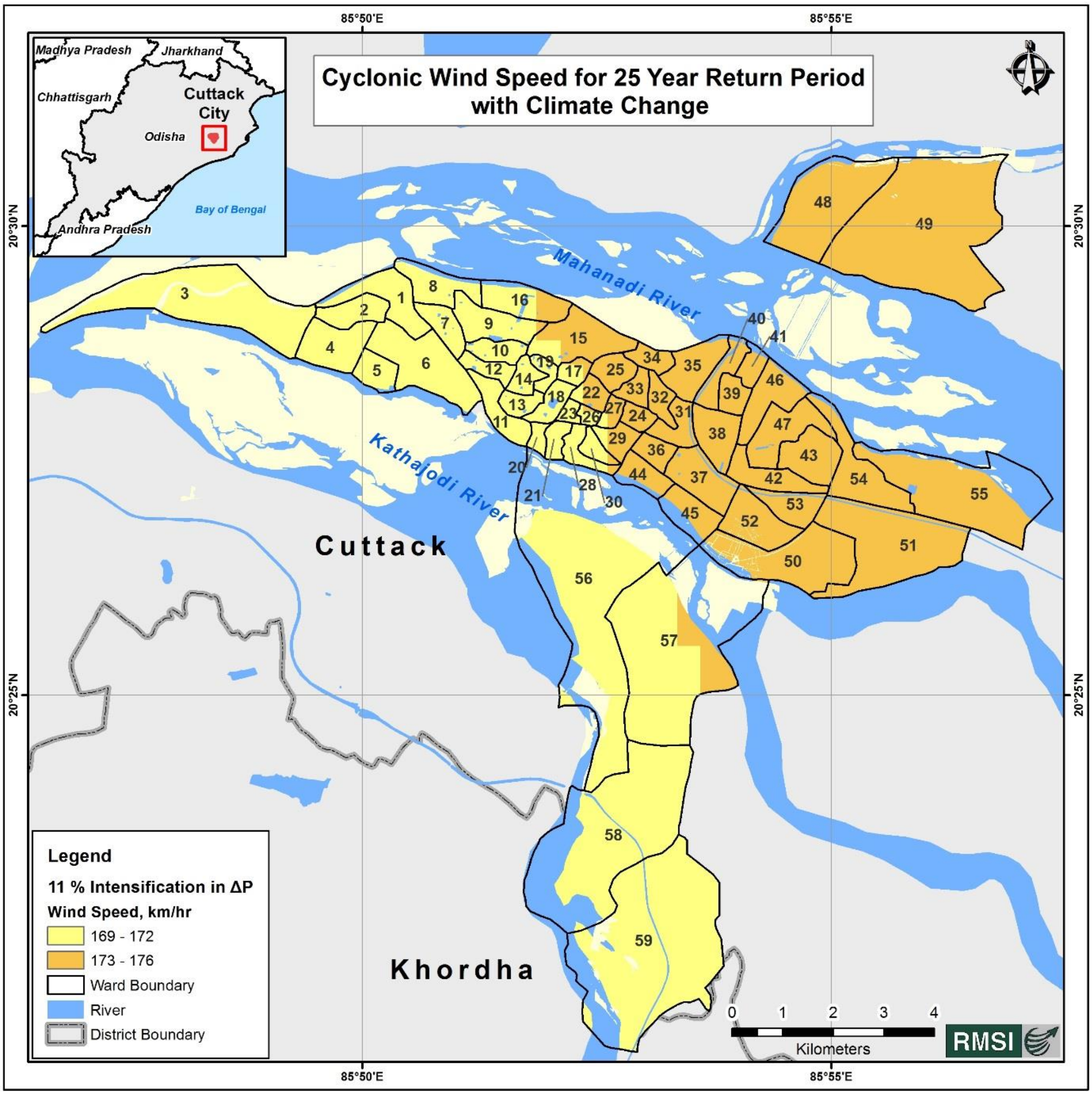

Figure 8-27: Wind hazard map for 25-year return period with climate change impact of 11%

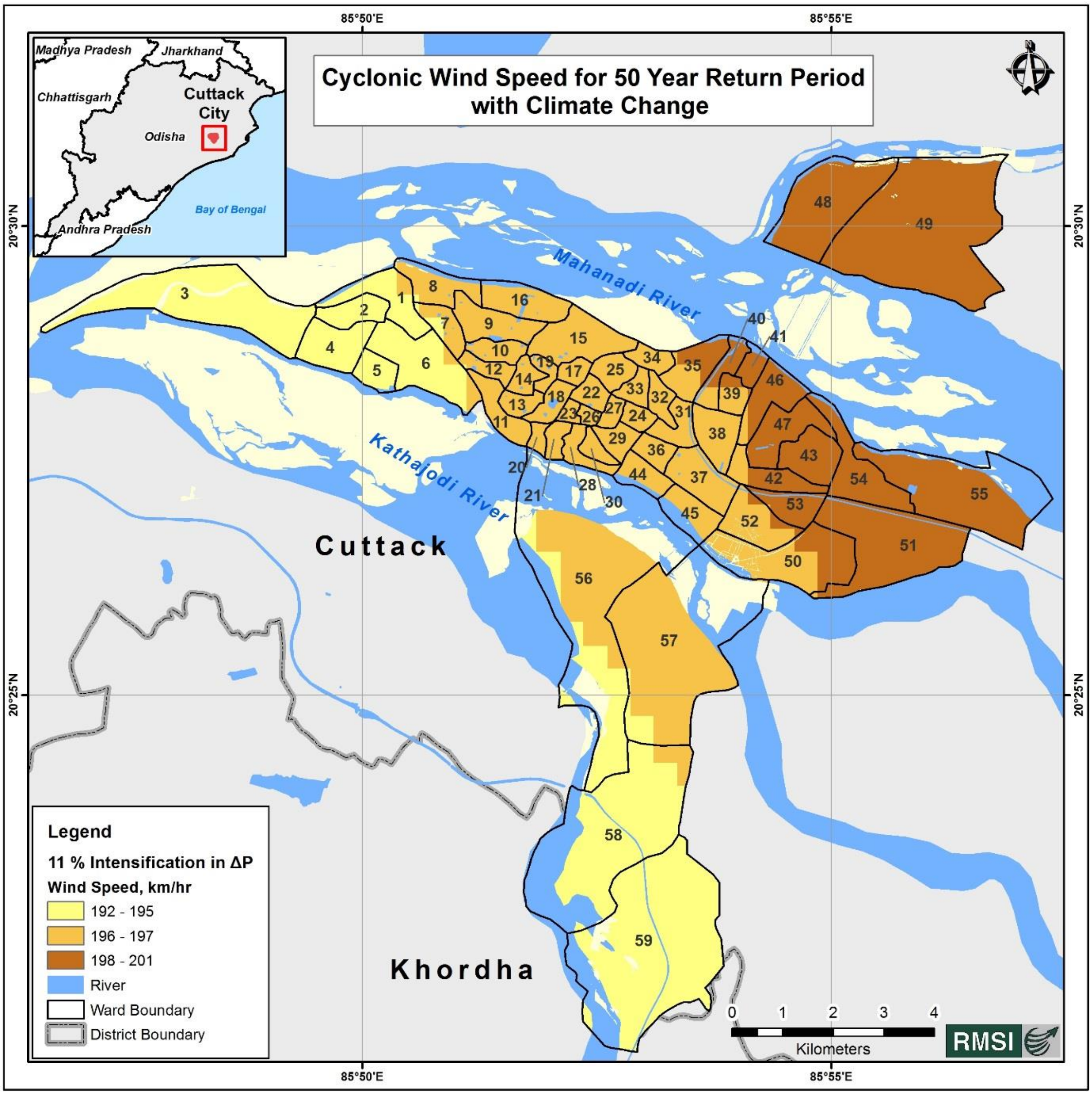

Figure 8-28: Wind hazard map for 50-year return period with climate change impact of 11%

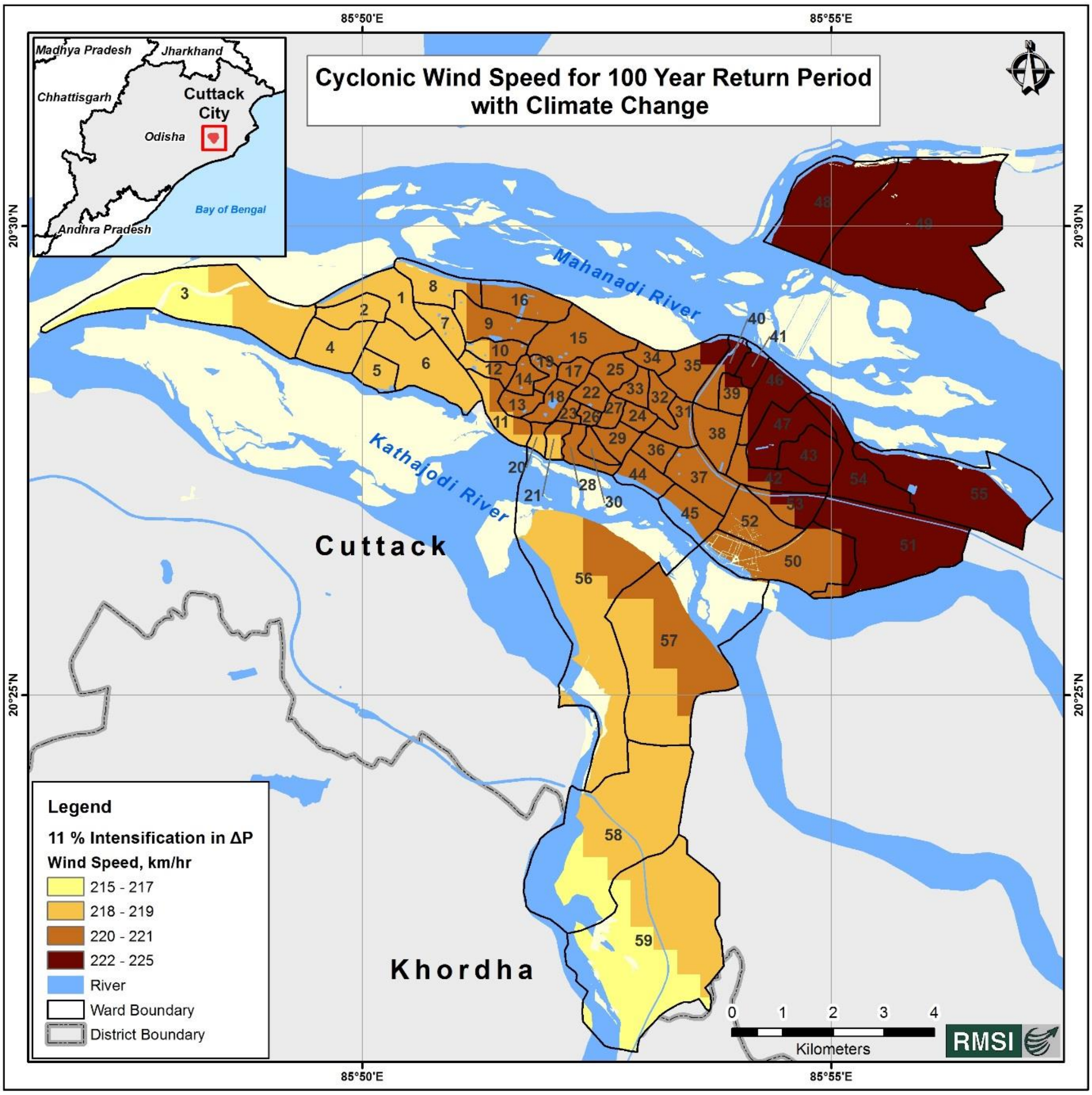

Figure 8-29: Wind hazard map for 100-year return period with climate change impact of 11%

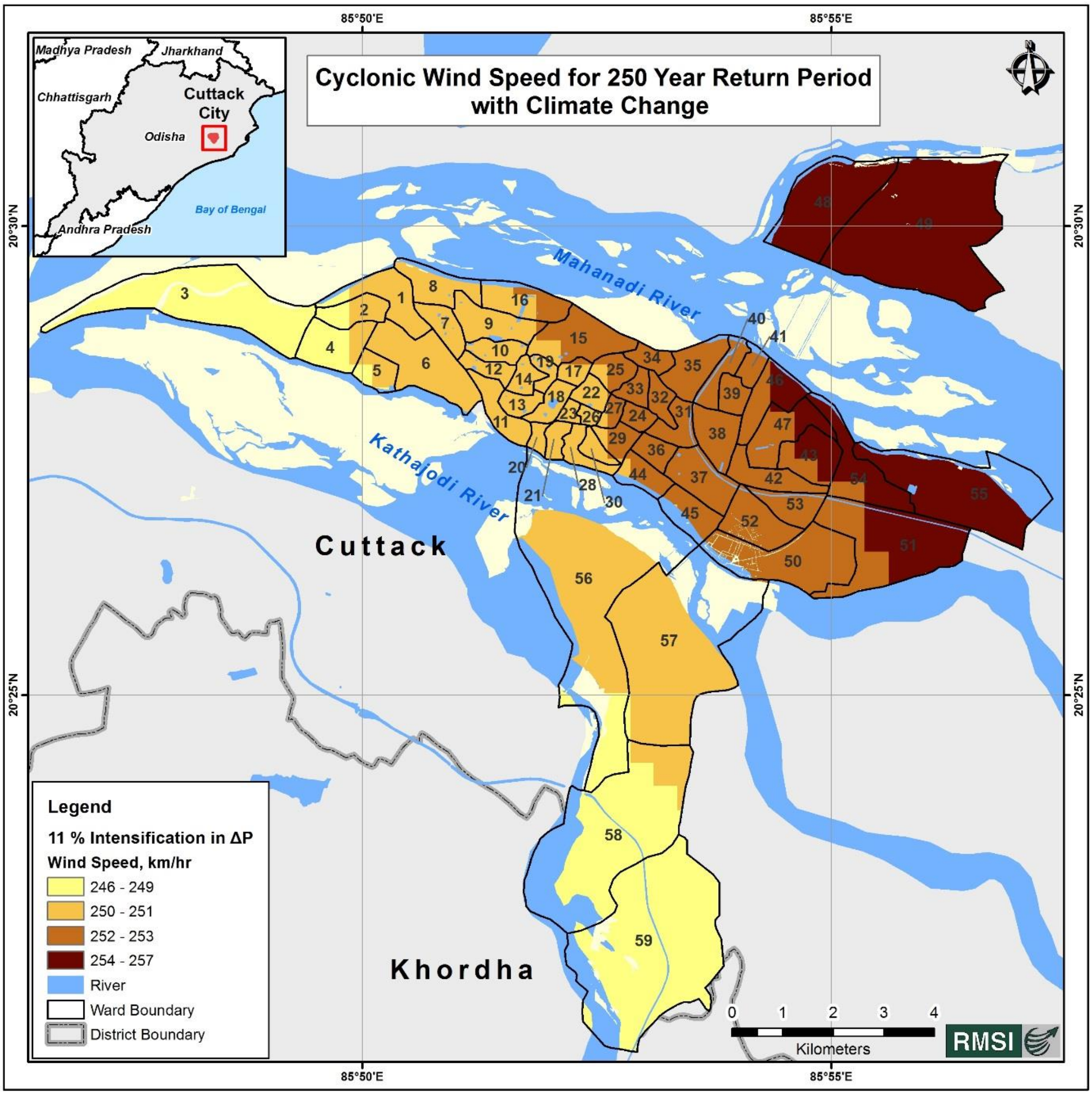

Figure 8-30: Wind hazard map for 250-year return period with climate change impact of 11%

8.5.3 FLOOD HAZARD MAPS-CURRENT CLIMATE

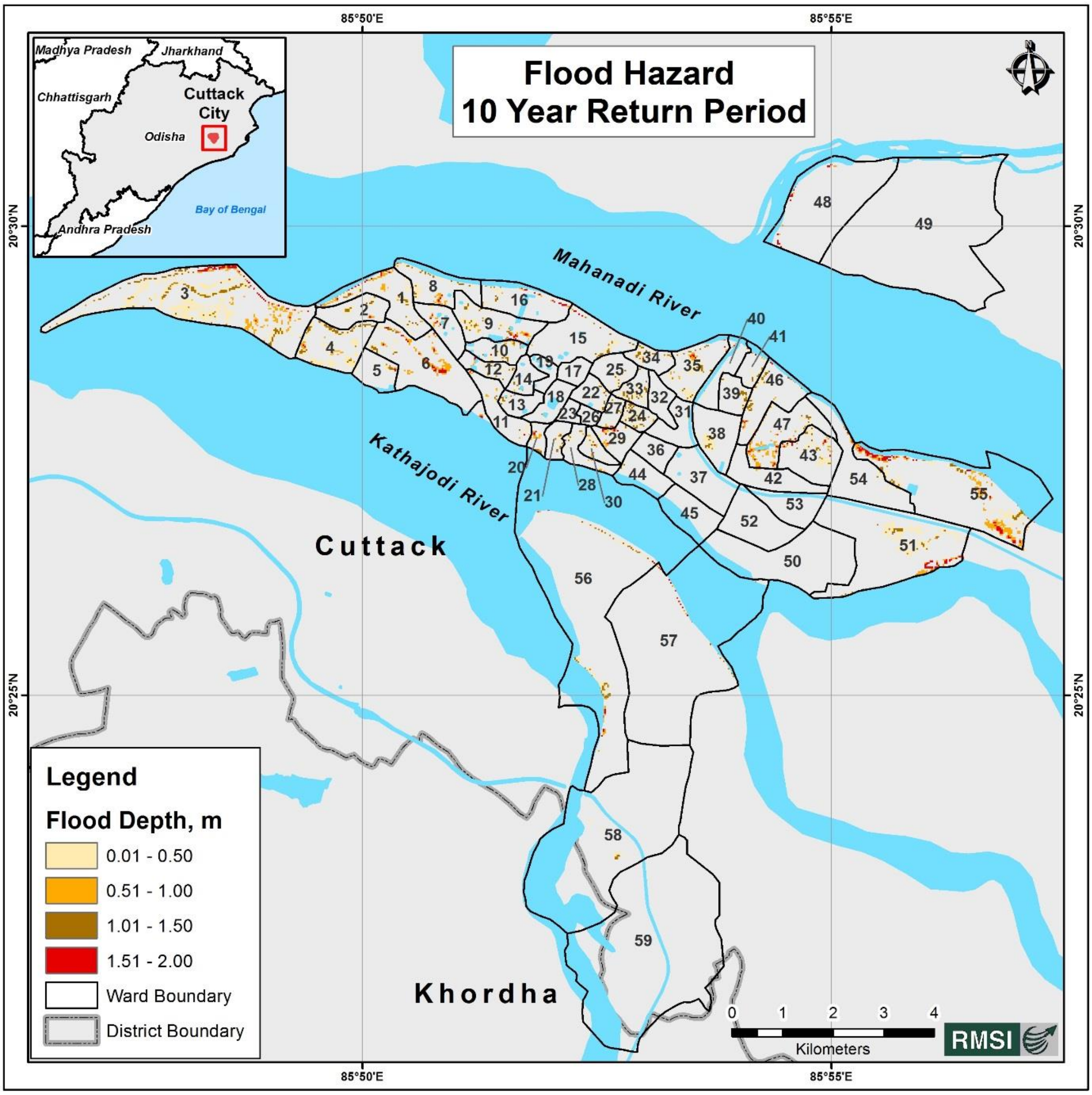

Figure 8-31: Flood Hazard Map for 10-year return period

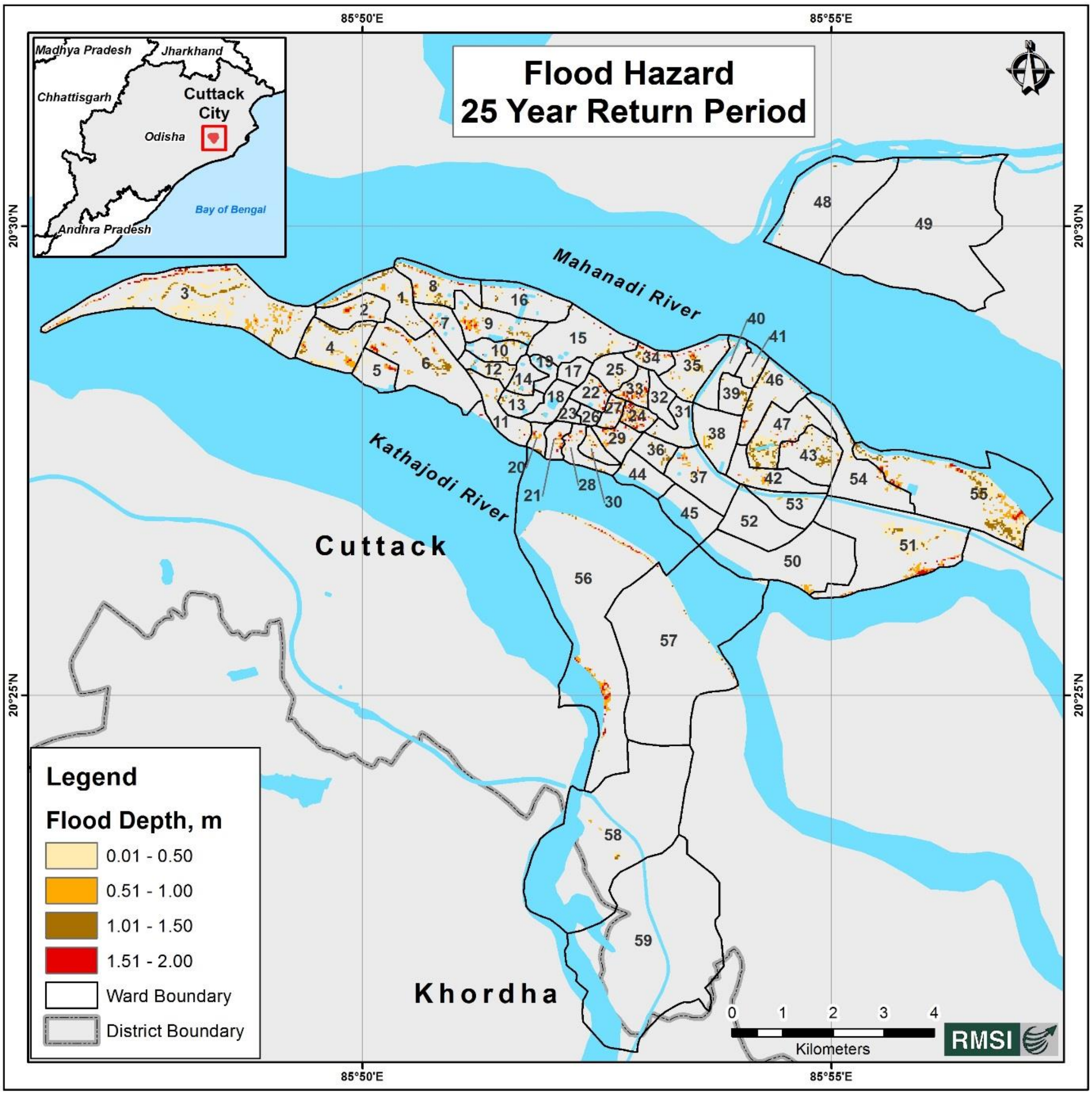

Figure 8-32: Flood Hazard Map for 25-year return period

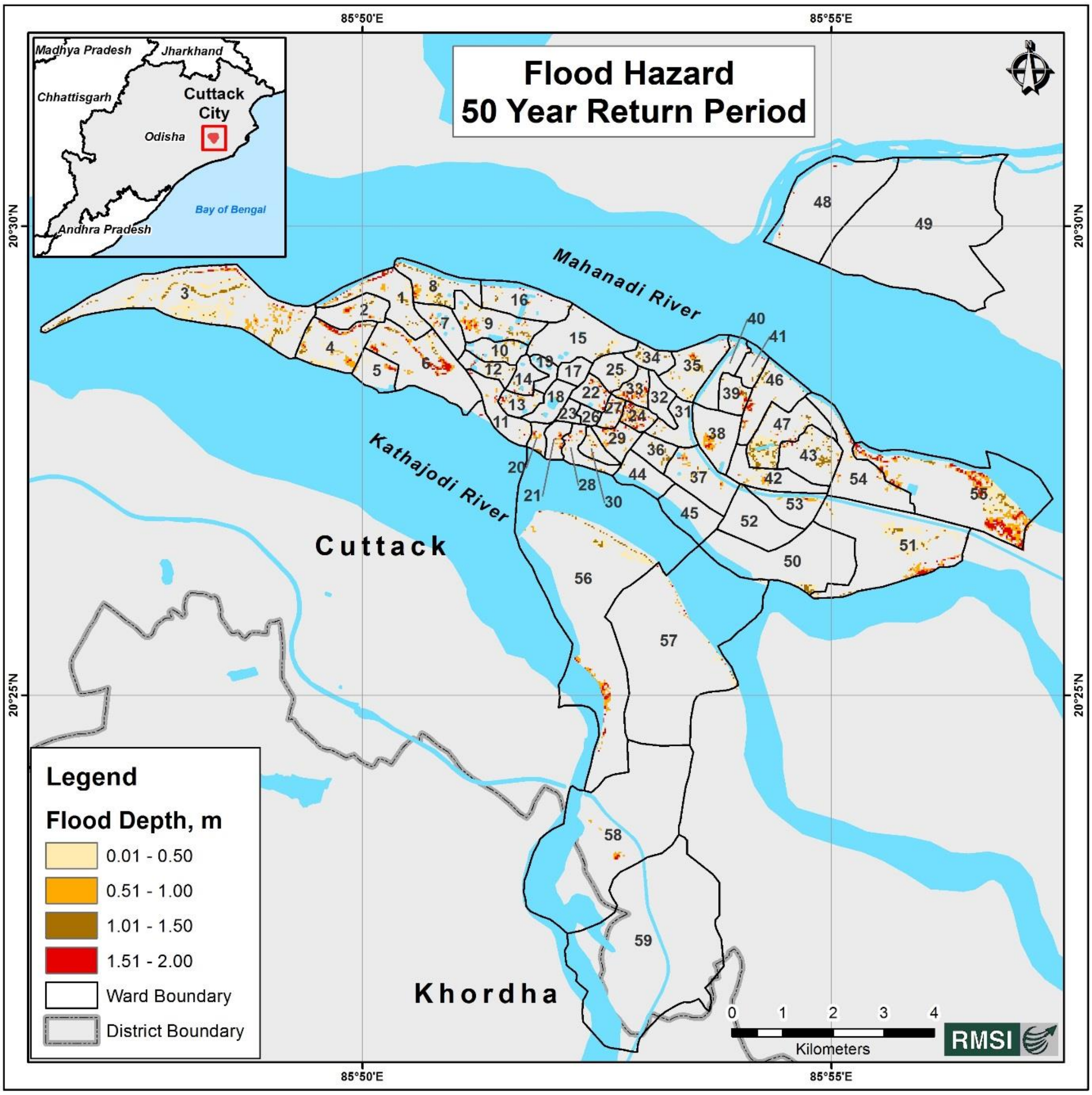

Figure 8-33: Flood Hazard Map for 50-year return period

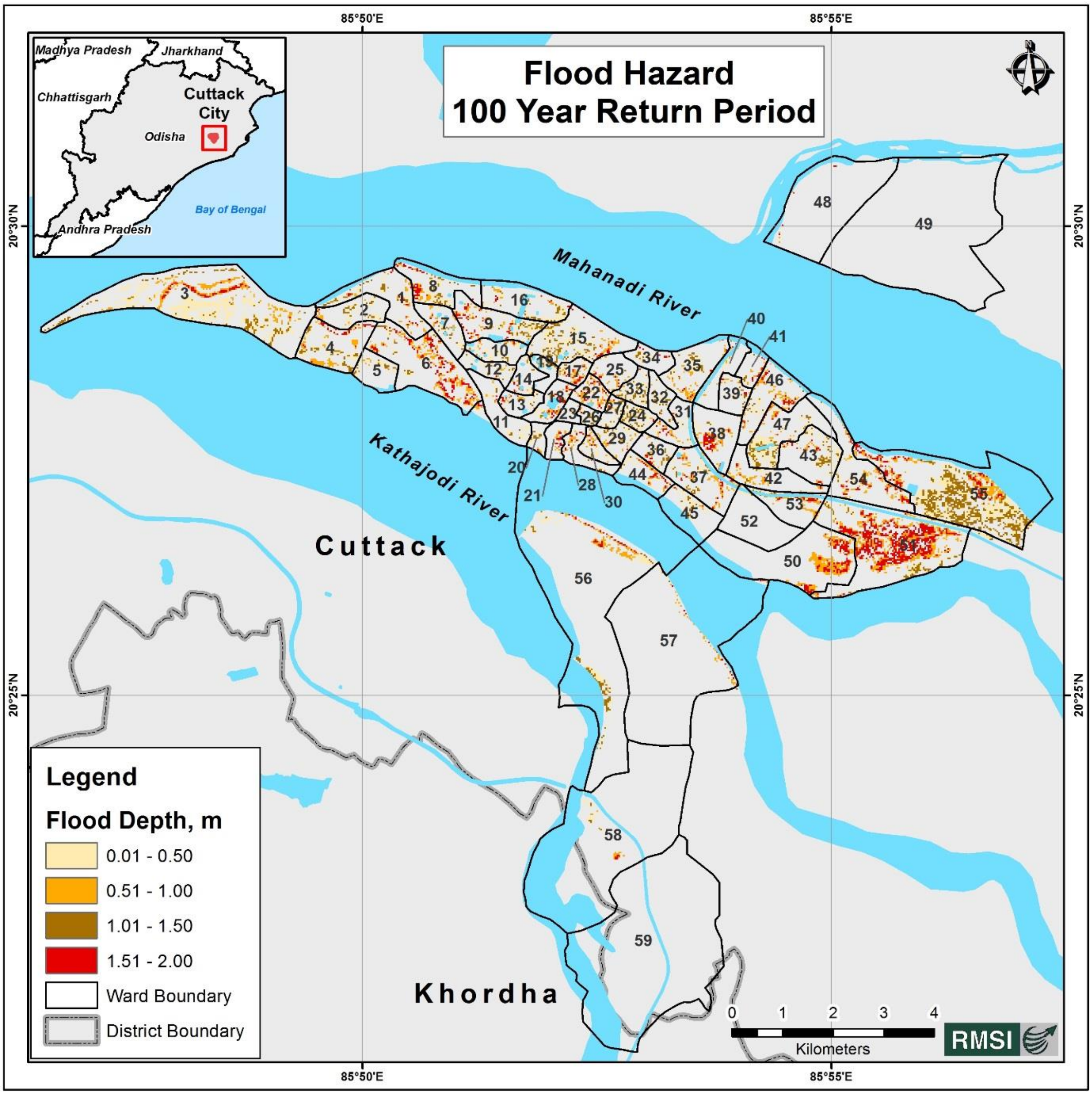

Figure 8-34: Flood Hazard Map for 100-year return period

8.5.4 FLOOD HAZARD MAPS-PROJECTED FUTURE CLIMATE

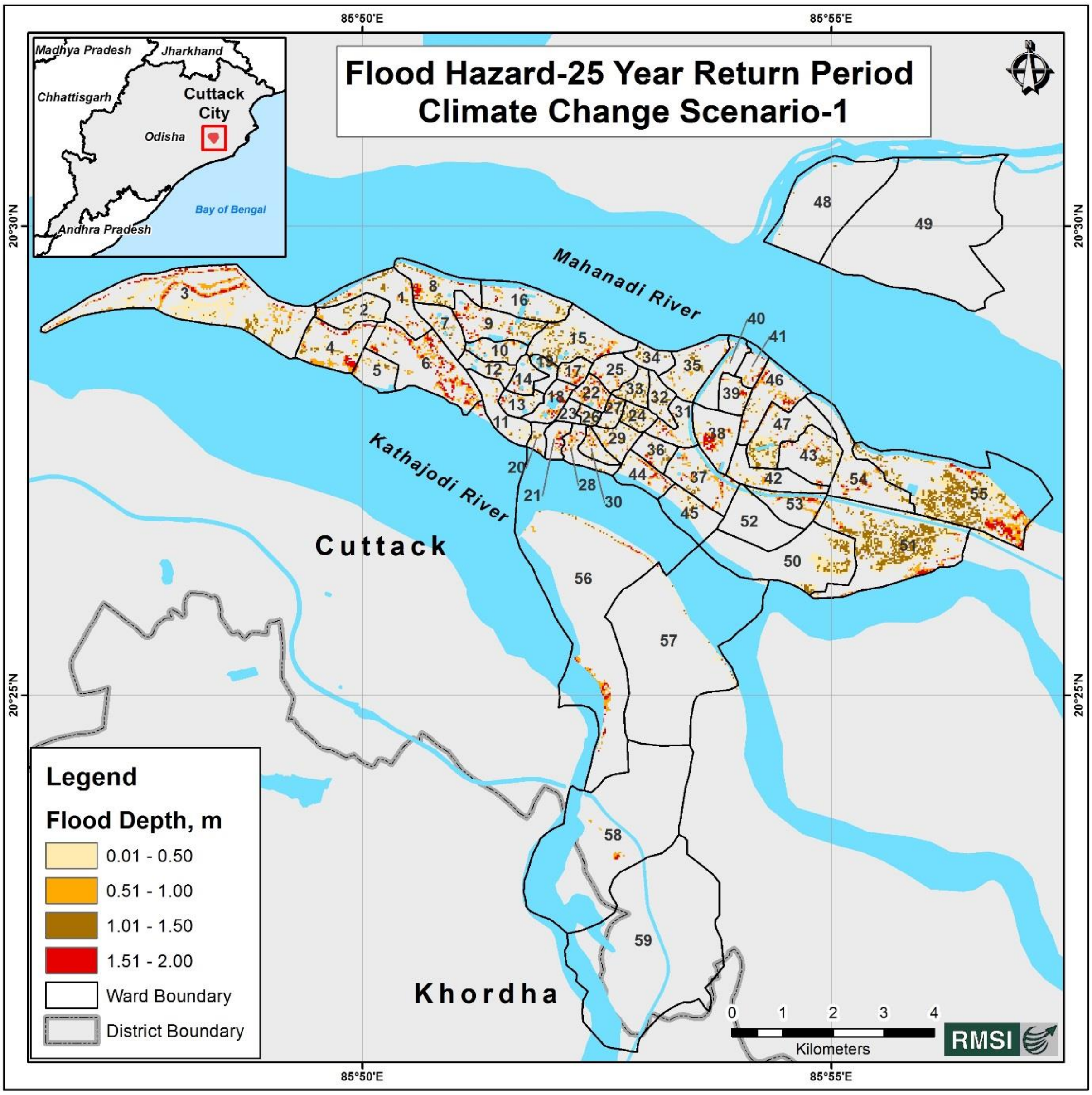

Figure 8-35: Flood Hazard Map for 25-year return period with climate change scenario-1

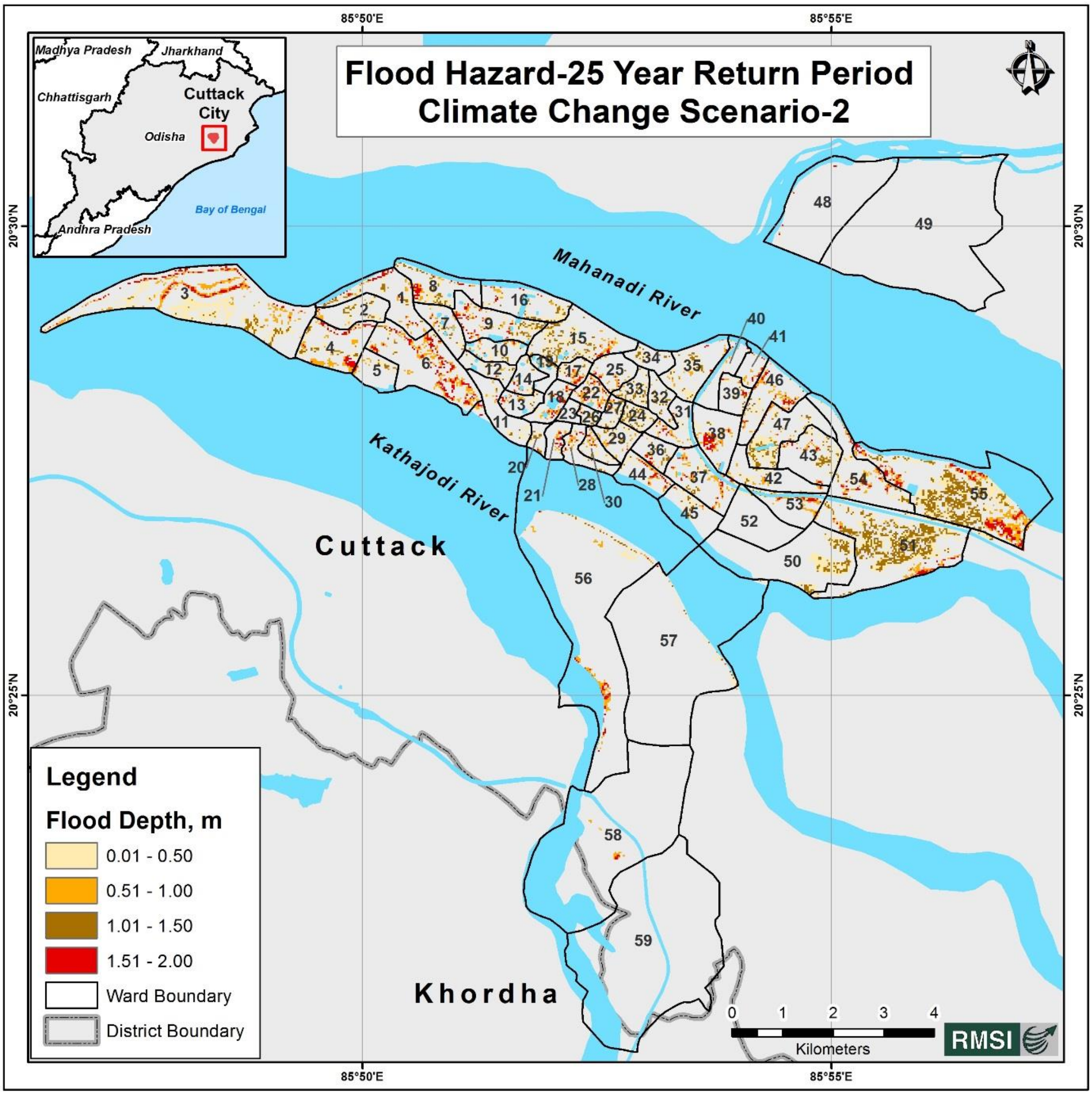

Figure 8-36: Flood Hazard Map for 25-year return period with climate change scenario-2

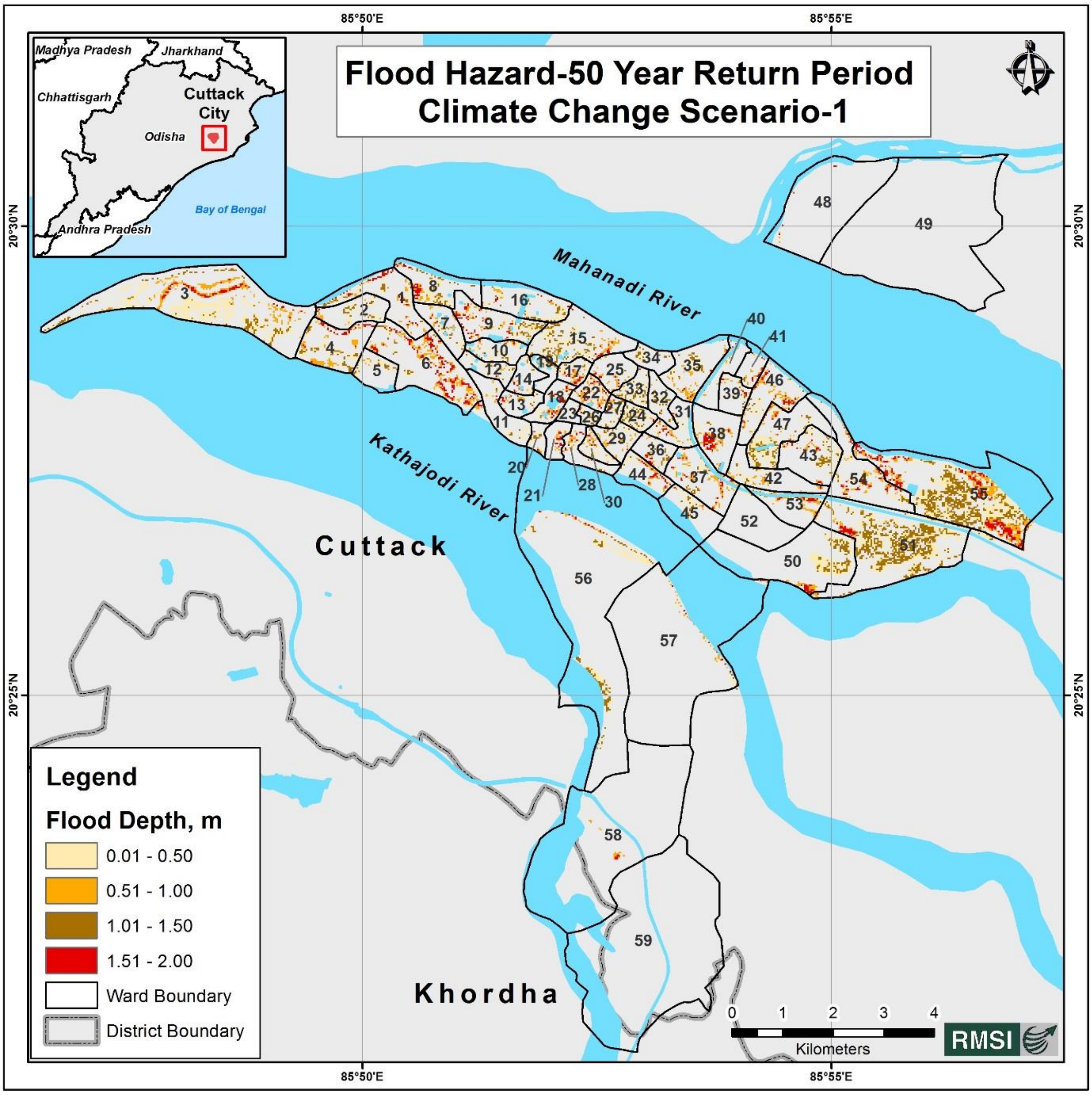

Figure 8-37: Flood Hazard Map for 50-year return period with climate change scenario-1

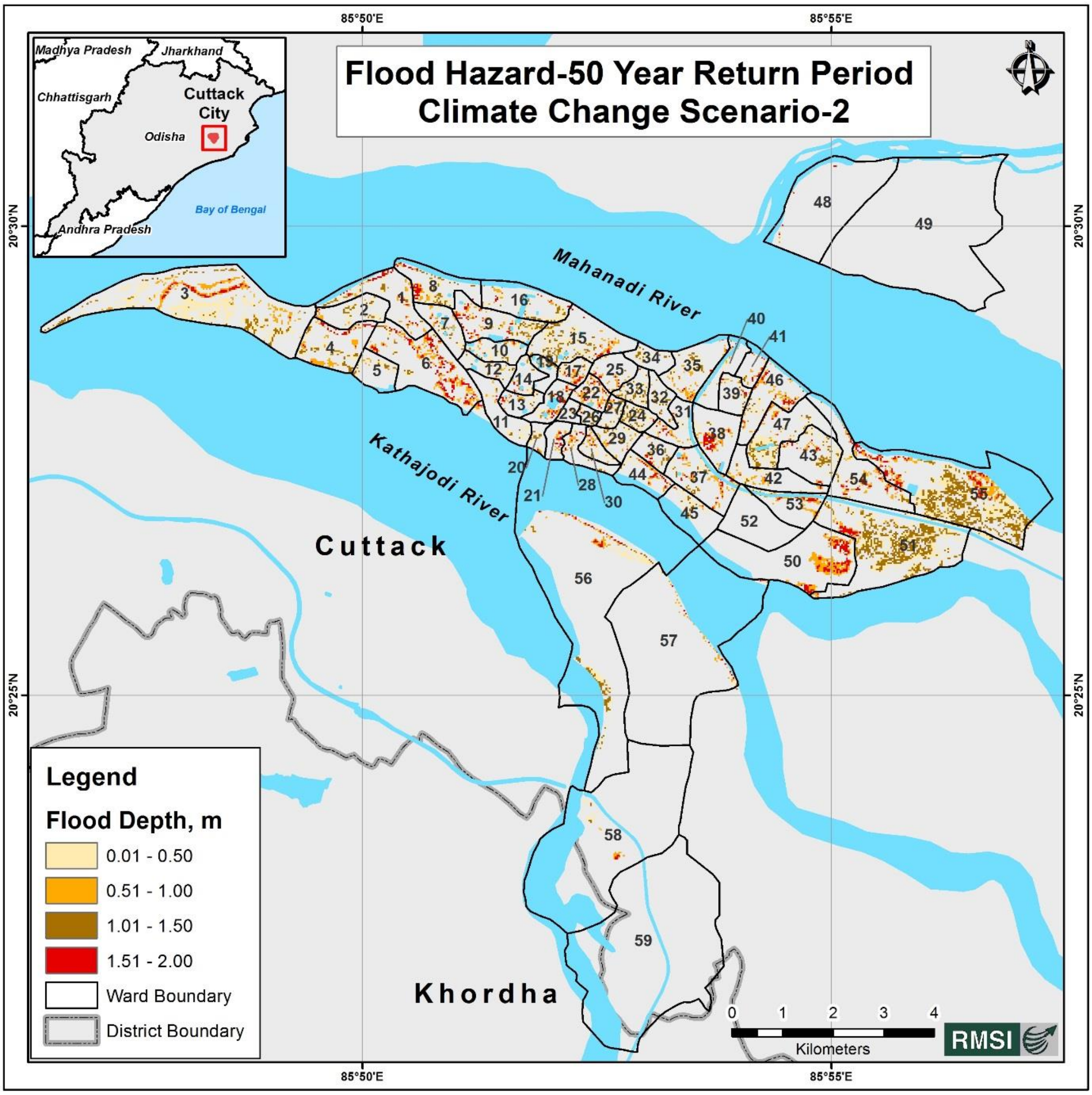

Figure 8-38: Flood Hazard Map for 50-year return period with climate change scenario-2

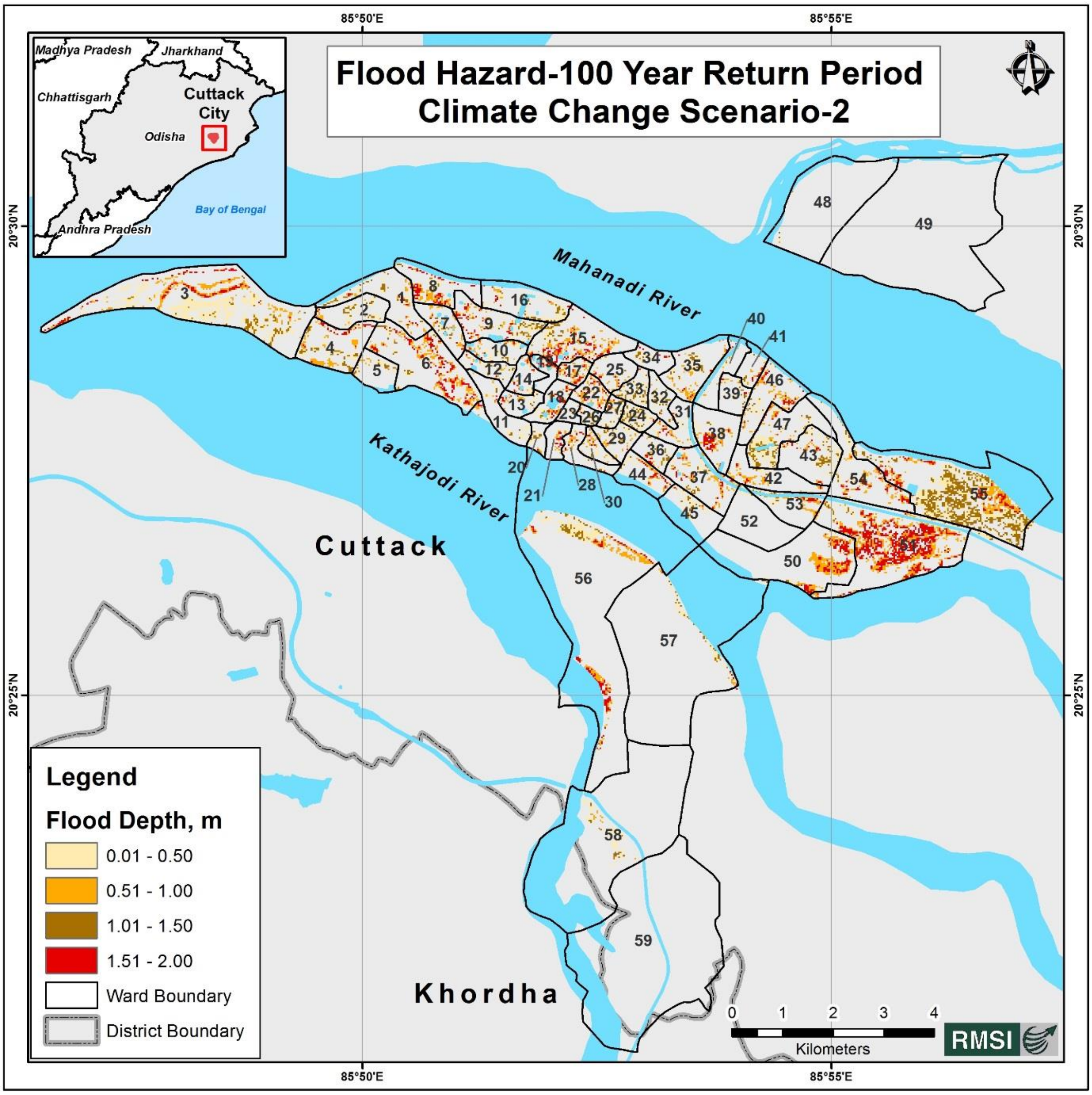

Figure 8-39: Flood Hazard Map for 100-year return period with climate change scenario-2

Table 8-6: Return period wise flood affected area (%)

Ward No.	Area (Sq. km)	Return period wise flood affected area (%)					
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
1	1.05	8.1%	12.3%	12.7%	13.5%	13.7%	18.1%
2	0.60	12.4%	12.7%	15.0%	15.1%	15.1%	26.7%
3	3.80	18.6%	22.9%	26.0%	26.8%	27.4%	33.7%
4	1.04	16.2%	17.3%	18.8%	18.9%	18.9%	27.0%
5	0.48	2.3%	3.8%	3.8%	5.5%	5.5%	13.8%
6	1.84	7.4%	8.0%	9.0%	11.3%	13.2%	30.1%
7	0.51	4.8%	5.2%	5.2%	5.2%	5.2%	19.4%
8	0.85	9.2%	12.2%	18.4%	27.5%	28.3%	32.0%
9	0.93	14.7%	19.0%	19.4%	24.8%	24.8%	44.1%
10	0.43	9.8%	14.1%	14.1%	16.5%	16.7%	25.2%

Ward No.	Area (Sq. km)	Return period wise flood affected area (%)					
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
11	0.64	3.7%	4.2%	4.2%	4.2%	4.2%	9.9%
12	0.34	10.0%	11.6%	15.3%	15.9%	15.9%	18.0%
13	0.32	4.6%	6.4%	6.4%	7.8%	10.1%	15.9%
14	0.32	2.3%	4.9%	8.3%	11.7%	12.6%	18.9%
15	1.32	6.8%	6.9%	7.1%	7.1%	7.1%	39.0%
16	0.95	6.3%	7.5%	7.8%	12.6%	12.6%	34.6%
17	0.25						26.7%
18	0.40	6.0%	6.2%	7.1%	8.5%	8.7%	33.8%
19	0.22	0.0%	0.0%	0.0%	0.4%	1.2%	16.2%
20	0.18	15.4%	15.9%	15.9%	15.9%	15.9%	20.5%
21	0.27	9.5%	9.5%	14.7%	14.7%	16.0%	21.8%
22	0.33	4.1%	7.2%	8.3%	11.0%	11.0%	36.9%
23	0.15						8.5%
24	0.26	18.4%	34.0%	35.1%	35.4%	35.4%	58.7%
25	0.45	6.4%	7.2%	7.4%	7.6%	7.6%	14.4%
26	0.13						36.7%
27	0.21	15.8%	22.7%	24.4%	24.4%	24.4%	44.0%
28	0.39	4.7%	6.1%	7.3%	8.5%	8.5%	16.0%
29	0.39	10.0%	10.8%	11.5%	12.2%	12.4%	21.0%
30	0.25	12.3%	13.0%	13.0%	14.8%	15.2%	22.8%
31	0.51	0.7%	5.0%	5.0%	7.7%	8.2%	20.3%
32	0.35	0.5%	0.5%	0.5%	0.5%	0.8%	27.7%
33	0.31	16.0%	29.7%	29.7%	29.7%	29.7%	52.4%
34	0.34	10.1%	13.1%	14.7%	14.7%	15.2%	19.0%
35	0.89	16.7%	19.7%	20.3%	20.9%	21.1%	25.2%
36	0.37				13.5%	13.5%	26.6%
37	1.00				3.4%	6.9%	21.8%
38	0.81		2.3%	7.3%	8.0%	9.5%	20.2%
39	0.38	12.6%	13.6%	14.1%	14.1%	14.1%	20.1%
40	0.52	8.0%	8.9%	8.9%	9.1%	9.1%	12.2%
41	0.31	21.9%	23.4%	23.7%	24.3%	24.3%	29.0%
42	0.74	0.4%	0.4%	0.4%	8.9%	9.1%	23.4%
43	0.93	4.3%	6.4%	10.7%	15.6%	15.6%	21.4%
44	0.53	1.9%	1.9%	1.9%	1.9%	1.9%	10.1%
45	0.74						11.3%
46	0.93	9.3%	10.3%	10.7%	12.1%	12.1%	22.8%
47	1.09	11.4%	15.5%	15.8%	30.2%	30.2%	32.4%
48	2.64	3.9%	4.1%	4.2%	4.3%	4.3%	4.4%
49	6.79						0.1%
50	2.36	0.0%	0.2%	0.3%	2.1%	3.8%	16.6%
51	3.22	3.2%	3.9%	6.3%	7.1%	7.9%	42.0%
52	1.02				0.2%	0.2%	1.0%

Ward No.	Area (Sq. km)	Return period wise flood affected area (%)					
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
53	0.64				2.7%	4.4%	17.4%
54	1.35	0.4%	0.6%	0.9%	2.3%	2.7%	17.2%
55	3.75	4.5%	8.0%	13.2%	21.0%	23.8%	53.5%
56	9.61	1.3%	2.1%	2.9%	3.3%	4.5%	5.6%
57	13.81	0.5%	0.6%	0.6%	0.8%	0.9%	0.9%
58	6.39		0.1%	0.3%	0.3%	0.3%	0.8%

Table 8-7: Return period wise average flood affected depth

Ward No.	Return period wise average flood depth (m)					
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
1	0.65	0.73	0.89	0.99	1.09	1.23
2	0.71	0.81	0.82	0.95	1.16	1.22
3	0.45	0.55	0.58	0.68	0.75	0.86
4	0.37	0.43	0.46	0.53	0.57	0.99
5	0.70	0.80	0.94	0.99	1.03	1.10
6	0.62	0.86	1.04	1.07	1.11	1.61
7	0.91	1.02	1.07	1.08	1.09	1.29
8	1.50	1.60	1.62	1.70	1.75	1.81
9	0.70	0.85	0.90	0.92	0.97	1.88
10	0.60	0.66	0.67	0.70	0.75	1.02
11	0.65	0.75	0.82	0.90	0.96	1.05
12	0.62	0.73	0.83	0.95	1.07	1.36
13	1.50	1.60	1.78	1.78	1.80	1.85
14	1.20	1.24	1.41	1.47	1.52	1.60
15	1.13	1.56	1.78	2.05	2.23	2.30
16	1.15	1.50	1.53	1.57	1.88	1.90
17						1.06
18	1.56	1.73	1.87	1.88	2.00	2.44
19				0.80	0.85	1.56
20	0.95	1.02	1.03	1.03	1.03	1.05
21	1.01	1.31	1.40	1.74	1.79	1.92
22	0.94	1.10	1.26	1.28	1.45	1.71
23						1.08
24	0.95	1.05	1.27	1.41	1.43	1.50
25	0.60	0.63	0.66	0.68	0.71	1.24
26						0.98
27	0.84	0.91	1.05	1.13	1.14	1.20
28	0.90	0.95	1.00	1.11	1.21	1.25
29	0.81	0.86	0.88	0.94	0.97	1.13
30	0.71	0.77	0.80	0.85	0.89	0.93
31	0.48	0.49	0.52	0.75	0.76	1.02
32	0.10	0.17	0.40	0.55	0.58	1.37
33	0.70	0.85	1.07	1.21	1.23	1.30
34	1.02	1.10	1.18	1.31	1.36	1.40
35	0.79	0.86	0.92	0.98	1.02	1.30
36				0.81	0.82	1.25
37				0.50	0.72	1.07
38		0.19	0.22	0.59	0.91	1.16
39	0.90	0.93	0.96	1.02	1.04	1.21
40	1.30	1.30	1.36	1.40	1.45	1.67
41	1.34	1.52	1.67	1.81	1.93	2.14
42	0.01	0.34	0.69	0.70	0.74	1.05
43	0.65	0.75	0.80	0.90	0.93	1.07

Ward No.	Return period wise average flood depth (m)					
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
44	0.24	0.28	0.29	0.29	0.29	0.91
45						0.63
46	0.64	0.77	0.88	0.89	0.93	1.16
47	0.30	0.49	0.55	0.60	0.61	0.93
48	2.55	3.21	3.60	3.99	4.32	4.51
49			0.09	0.56	0.86	0.90
50	0.01	0.35	0.60	0.68	0.75	1.02
51	0.43	0.51	0.55	0.58	0.64	1.43
52				0.18	0.25	0.56
53				0.52	0.78	1.10
54	0.50	0.55	0.61	0.66	0.78	1.43
55	0.60	0.99	1.15	1.15	1.30	1.35
56	1.89	2.02	2.05	2.17	2.20	2.25
57	2.19	2.40	2.60	2.77	2.92	3.24
58		0.24	0.41	0.73	0.96	0.99

8.6 Annexure 3: Detailed Exposure Data

Table 8-8: Ward-level distribution of population and buildings based on uses

Ward	Male Population	Female Population	Total Population	Residential	Commercial	Industrial	Educational Institutes	Health Facilities	Religious Places
1	11,244	11,655	22,899	4,455	0	0	29	23	50
2	2,496	2,182	4,678	1,028	0	0	7	5	11
3	3,494	3,054	6,549	1,439	0	0	9	7	16
4	3,994	3,491	7,484	1,644	0	0	11	8	18
5	4,913	5,104	10,016	2,085	0	0	14	11	23
6	6,316	6,562	12,878	2,680	669	0	18	14	30
7	5,310	5,889	11,199	2,322	0	0	15	12	26
8	5,487	4,633	10,120	2,020	0	0	13	10	23
9	5,606	5,609	11,216	2,390	14	0	16	12	27
10	7,400	7,031	14,431	2,713	102	0	18	14	30
11	7,816	7,184	15,000	2,836	619	0	19	14	32
12	6,762	6,288	13,050	2,783	0	0	18	14	31
13	6,124	5,247	11,370	2,209	54	0	14	11	25
14	6,619	5,181	11,800	2,199	0	0	14	11	24
15	7,517	7,185	14,703	2,966	492	0	19	15	33
16	5,217	5,390	10,608	2,317	0	0	15	12	26
17	5,235	5,434	10,669	2,169	390	0	14	11	24
18	5,601	4,729	10,330	1,965	1,074	0	13	10	22
19	7,584	6,211	13,795	2,501	0	0	16	13	28
20	3,203	2,319	5,522	944	511	0	6	5	11
21	4,042	3,737	7,779	1,460	1,017	0	10	7	16
22	7,679	5,760	13,439	2,504	499	0	16	13	28
23	5,705	4,283	9,987	1,656	328	3	11	8	18
24	3,608	2,739	6,347	1,243	183	0	8	6	14
25	6,750	6,490	13,240	3,363	1,075	0	17	13	28
26	9,003	8,608	17,612	1,864	149	0	22	17	37
27	5,412	4,108	9,520	2,550	151	0	12	9	21
28	6,129	6,229	12,359	2,265	65	0	15	11	25
29	6,544	6,229	12,773	2,357	1,551	0	15	12	26
30	4,653	4,416	9,069	1,882	213	0	12	10	21
31	5,936	5,688	11,624	2,420	1,405	0	16	12	27
32	5,716	5,444	11,161	2,097	1,116	1	14	11	23
33	6,206	5,798	12,004	2,462	787	0	16	12	27
34	5,851	5,495	11,346	2,248	798	0	15	11	25
35	5,371	6,516	11,886	1,971	189	0	13	10	22
36	4,523	4,293	8,815	1,884	1,020	0	12	10	21
37	6,389	5,883	12,272	2,408	1,232	0	16	12	27
38	4,300	3,762	8,063	2,058	2,150	4	13	10	23
39	5,548	4,974	10,521	2,223	103	0	15	11	25
40	4,049	3,752	7,800	1,608	566	0	11	8	18
41	5,568	5,257	10,824	2,197	102	0	14	11	24
42	5,480	6,173	11,653	2,176	461	68	14	11	24
43	4,797	4,286	9,083	1,966	1,001	0	13	10	22
44	4,986	4,550	9,536	2,268	975	0	15	12	25
45	5,973	5,479	11,452	2,310	877	0	15	12	26
46	5,814	5,120	10,934	2,390	1,873	0	16	12	27
47	8,417	7,928	16,344	3,575	1,128	0	23	18	40
48	6,165	5,792	11,957	2,566	8	39	17	13	29
49	6,993	6,318	13,311	2,900	3,031	2,028	19	15	32
50	7,289	6,299	13,588	3,009	871	364	20	15	34
51	6,140	5,613	11,753	2,406	1,607	0	16	12	27
52	6,883	6,344	13,227	3,053	575	8	20	15	34

Ward	Male Population	Female Population	Total Population	Residential	Commercial	Industrial	Educational Institutes	Health Facilities	Religious Places
53	4,673	4,125	8,798	2,006	88	0	13	10	22
54	5,929	5,688	11,618	2,642	308	14	17	13	29
55	5,833	5,646	11,479	2,324	0	3	15	12	25
56	7,311	6,791	14,101	2,632	3,762	12	17	13	29
57	5,886	5,388	11,274	2,126	3,261	9	14	11	24
58	2,622	2,477	5,099	940	322	0	6	5	10
59	3,492	3,665	7,157	1,316	2,139	67	9	7	15
Grand Total	341,603	317,521	659,122	132,990	40,916	2,621	870	672	1,480

Table 8-9: Classification of structure based on wall and roof combination

Sl. No.	Building Category	Structural Types (combination of major wall and roof materials)
1	ST1	Grass/Thatch/ Bamboo/Wood/Mud etc. used as roof in combination of Grass/thatch/bamboo etc. as wall material
2	ST2	Grass/ thatch/ bamboo/ wood/ plastic/ polythene etc. used as roof material in combination of Mud/ unburnt brick and stone not packed with mortar as wall materials
3	ST3	Grass/Thatch/ Bamboo/Wood/Mud etc. with material of wall Wood
4	ST4	Grass/ thatch/ bamboo/ wood/ plastic/ polythene etc. used as roof material in combination of burnt brick/ stone packed with mortar/concrete as wall materials
5	ST5	Plastic/ Polythene roof with material of wall Grass/thatch/bamboo etc.
6	ST6	Handmade tiles/ machine made tiles/burnt bricks/stone/slate/concrete used as roof material in combination of Grass/thatch/bamboo etc. as wall material
7	ST7	Handmade tiles/ machine made tiles used as roof material in combination of Mud/unburnt brick/stone not packed with mortar as wall material
8	ST8	Handmade tiles/ machine made tiles used as roof material in combination of stone packed with mortar/burnt brick/concrete as wall material
9	ST9	Handmade tiles/ machine made tiles/burnt bricks/stone/slate/concrete used as roof material in combination of wood as wall material
10	ST10	Burnt bricks/stone/slate used as roof material in combination of Mud/unbrunt brick as wall material
11	ST11	Burnt bricks/stone/slate used as roof material in combination of Stone packed with mortar/burnt brick/concrete as wall material
12	ST12	G.I./Metal/Asbestos sheets with material of wall Grass/thatch/bamboo etc.
13	ST13	G.I./Metal/Asbestos sheets used as roof material in combination of Mud/unburnt brick/Stone not packed with mortar as wall material
14	ST14	G.I./Metal/Asbestos sheets with material of wall Wood
15	ST15	G.I./Metal/Asbestos sheets with material of wall G.I./metal/asbestos sheets with material of wall
16	ST16	G.I./Metal/Asbestos sheets used as roof material in combination of Stone packed with mortar/ burnt brick/ concrete as wall material
17	ST17	Concrete used as roof material in combination of Mud/unburnt brick/Stone not packed with mortar as wall material
18	ST18	Concrete used as roof material in combination of Burnt brick/Stone packed with mortar/Concrete as wall material
19	ST19	Plastic/ Polythene used as roof material in combination of Wood wall material
20	ST20	Plastic/ Polythene used as roof material in combination of Stone not packed with mortar wall material
21	ST21	Burnt Brick used as roof material in combination of Stone not packed with mortar as wall material

Sl. No.	Building Category	Structural Types (combination of major wall and roof materials)
22	ST22	Stone/Slate used as roof material in combination of Stone not packed with mortar as wall material
23	ST23	Plastic/ Polythene used as roof material in combination of Mud/unburnt brick as wall material
24	ST24	Plastic/ Polythene used as roof material in combination of Stone packed with mortar as wall material
25	ST_Other	Any Other

Table 8-10: Ward-level estimated exposure value for different houses by occupancy and uses (in crores)

Ward	Residential	Commercial	Industrial	Educational Institutes	Health Facilities	Religious Places
1	254.59	0	0	26.39	11.79	1.92
2	59.35	0	0	6.37	2.56	0.42
3	62.32	0	0	8.19	3.59	0.61
4	94.17	0	0	10.01	4.10	0.69
5	119.49	0	0	12.74	5.64	0.88
6	143.09	42.16	0	16.38	7.18	1.15
7	135.73	0	0	13.65	6.15	1.00
8	118.72	0	0	11.83	5.13	0.88
9	137.76	0.81	0	14.56	6.15	1.04
10	158.35	5.97	0	16.38	7.18	1.15
11	165.31	39.15	0	17.29	7.18	1.23
12	162.44	0	0	16.38	7.18	1.19
13	125.59	3.44	0	12.74	5.64	0.96
14	128.38	0	0	12.74	5.64	0.92
15	119.48	30.71	0	17.29	7.69	1.27
16	132.92	0	0	13.65	6.15	1.00
17	131.17	24.66	0	12.74	5.64	0.92
18	104.16	65.76	0	11.83	5.13	0.85
19	145.62	0	0	14.56	6.66	1.08
20	55.50	32.33	0	5.46	2.56	0.42
21	85.01	64.36	0	9.10	3.59	0.61
22	153.37	31.58	0	14.56	6.66	1.08
23	95.77	20.73	2.03	10.01	4.10	0.69
24	75.06	11.59	0	7.28	3.08	0.54
27	155.02	9.57	0	10.92	4.61	0.81
25	195.43	68.00	0	15.47	6.66	1.08
26	108.96	9.43	0	20.02	8.71	1.42
28	133.32	4.14	0	13.65	5.64	0.96
29	142.43	98.09	0	13.65	6.15	1.00
30	110.44	13.45	0	10.92	5.13	0.81
31	142.68	88.24	0	14.56	6.15	1.04
32	117.69	51.48	0.30	12.74	5.64	0.88
33	144.18	49.83	0	14.56	6.15	1.04
34	128.64	47.29	0	13.65	5.64	0.96
35	92.13	10.90	0	11.83	5.13	0.85
36	109.33	62.07	0	10.92	5.13	0.81
37	140.11	72.16	0	14.56	6.15	1.04
38	117.18	123.18	2.41	11.83	5.13	0.88
39	129.93	6.01	0	13.65	5.64	0.96
40	94.12	33.15	0	10.01	4.10	0.69
41	117.60	5.93	0	12.74	5.64	0.92

Ward	Residential	Commercial	Industrial	Educational Institutes	Health Facilities	Religious Places
42	125.42	27.35	39.95	12.74	5.64	0.92
43	111.65	58.34	0	11.83	5.13	0.85
44	122.01	55.92	0	13.65	6.15	0.96
45	124.76	30.00	0	13.65	6.15	1.00
46	132.19	109.30	0.24	14.56	6.15	1.04
47	209.00	68.08	0	20.93	9.23	1.54
48	97.21	0.33	22.82	15.47	6.66	1.11
49	111.45	113.32	1,193.54	17.29	7.69	1.23
50	143.12	32.26	214.04	18.20	7.69	1.31
51	106.96	67.11	0	14.56	6.15	1.04
52	165.14	33.52	4.95	18.20	7.69	1.31
53	116.05	5.10	0	11.83	5.13	0.85
54	148.81	18.08	8.19	15.47	6.66	1.11
55	103.63	0	1.82	13.65	6.15	0.96
56	93.33	211.17	7.08	15.47	6.66	1.11
57	68.29	190.01	5.39	12.74	5.64	0.92
58	37.49	14.05	0	5.46	2.56	0.38
59	45.50	124.64	39.70	8.19	3.59	0.58
Grand Total	7,204.55	2,284.72	1,542.46	791.70	344.40	56.86

Table 8-11: Ward-level estimated length for different types of roads and power line (in KM) and their exposure value

Ward	Total Length of State Highway (in KM)	Total Length of Major Road (in KM)	Total Length of Minor Road (in KM)	Total Length of Link Road (in KM)	Total Replacement Cost of State Highway (in INR crores)	Total Replacement Cost of Major Road (in INR crores)	Total Replacement Cost of Minor Road (in INR crores)	Total Replacement Cost of Link Road (in INR crores)	Total Length of Main Power Line (in km)	Total Replacement Cost of Main Power Line (in crores)
1	0	5.11	0	11.68	0	25.55	0	14.60	15.83	0.70
2	0	1.70	0	10.38	0	8.50	0	12.98	10.56	0.47
3	0	3.13	0	34.22	0	15.63	0	42.77	32.64	1.45
4	0	0	0	20.36	0	0	0	25.45	17.80	0.79
5	0	0.67	0	6.81	0	3.36	0	8.52	6.93	0.31
6	0	4.82	0	21.20	0	24.10	0	26.50	24.09	1.07
7	0	1.47	0	5.77	0	7.35	0	7.21	6.73	0.30
8	0	1.70	0	8.31	0	8.52	0	10.39	8.95	0.40
9	0	1.72	0.39	6.80	0	8.60	0.97	8.51	8.35	0.37
10	0	1.31	0.11	4.04	0	6.54	0.28	5.06	5.33	0.24
11	0	0.54	0	9.24	0	2.71	0	11.54	8.31	0.37
12	0	0.04	0	4.93	0	0.18	0	6.17	4.74	0.21
13	0	0.29	0	4.49	0	1.47	0	5.61	4.64	0.21
14	0	0.85	0	4.64	0	4.23	0	5.80	5.41	0.24
15	0	2.79	0	11.73	0	13.93	0	14.67	13.75	0.61
16	0	2.84	0	9.15	0	14.20	0	11.43	11.00	0.49
17	0	0	0	3.95	0	0	0	4.94	3.83	0.17
18	0	0.70	0	4.25	0	3.52	0	5.31	4.84	0.21
19	0	0	0	2.35	0	0	0	2.94	2.28	0.10
20	0	0.33	0	2.69	0	1.63	0	3.37	2.99	0.13

Ward	Total Length of State Highway (in KM)	Total Length of Major Road (in KM)	Total Length of Minor Road (in KM)	Total Length of Link Road (in KM)	Total Replacement Cost of State Highway (in INR crores)	Total Replacement Cost of Major Road (in INR crores)	Total Replacement Cost of Minor Road (in INR crores)	Total Replacement Cost of Link Road (in INR crores)	Total Length of Main Power Line (in km)	Total Replacement Cost of Main Power Line (in crores)
21	0	0.13	0	4.21	0	0.64	0	5.27	4.13	0.18
22	0	0.63	0.52	3.19	0	3.14	1.31	3.99	4.23	0.19
23	0	0.65	0.11	1.61	0	3.27	0.27	2.01	2.31	0.10
24	0	0	0	2.44	0	0	0	3.06	2.43	0.11
25	0	0.81	0.11	6.20	0	4.04	0.27	7.75	6.98	0.31
26	0	0.43	0.24	1.40	0	2.16	0.60	1.75	2.01	0.09
27	0	0.35	0	3.26	0	1.75	0	4.08	3.59	0.16
28	0	0	0	6.32	0	0	0	7.90	6.01	0.27
29	0	0.48	0	5.41	0	2.41	0	6.76	5.70	0.25
30	0	0	0	3.58	0	0	0	4.47	3.49	0.15
31	0	1.02	0	5.38	0	5.08	0	6.72	6.25	0.28
32	0	0.95	0	4.21	0	4.75	0	5.27	5.12	0.23
33	0	0	0	3.39	0	0	0	4.24	3.32	0.15
34	0	1.42	0	2.29	0	7.09	0	2.87	3.66	0.16
35	0	2.16	0	8.59	0	10.82	0	10.74	10.34	0.46
36	0	1.45	0	3.42	0	7.27	0	4.27	4.74	0.21
37	0	1.51	0	8.03	0	7.54	0	10.04	9.28	0.41
38	0	0.24	0.07	12.14	0	1.22	0.17	15.18	10.90	0.48
39	0	0	0	6.72	0	0	0	8.40	6.54	0.29
40	0	2.29	0	4.82	0	11.45	0	6.03	6.24	0.28
41	0	0.39	0	3.70	0	1.97	0	4.62	3.94	0.17
42	1.60	1.36	0	8.98	19.26	6.80	0	11.23	10.65	0.47

Ward	Total Length of State Highway (in KM)	Total Length of Major Road (in KM)	Total Length of Minor Road (in KM)	Total Length of Link Road (in KM)	Total Replacement Cost of State Highway (in INR crores)	Total Replacement Cost of Major Road (in INR crores)	Total Replacement Cost of Minor Road (in INR crores)	Total Replacement Cost of Link Road (in INR crores)	Total Length of Main Power Line (in km)	Total Replacement Cost of Main Power Line (in crores)
43	0	0.48	0	11.88	0	2.40	0	14.85	12.24	0.54
44	0	1.94	0.80	5.83	0	9.72	2.01	7.29	8.42	0.37
45	0	1.55	0	5.13	0	7.76	0	6.41	6.45	0.29
46	0	2.66	0	5.19	0	13.31	0	6.49	7.49	0.33
47	0	4.15	0	16.18	0	20.73	0	20.22	19.98	0.89
48	0	0	0	23.92	0	0	0	29.90	21.27	0.94
49	0	8.18	0	31.71	0	40.91	0	39.64	31.59	1.40
50	0	5.35	0	20.90	0	26.75	0	26.12	25.09	1.11
51	2.54	3.30	0	17.94	30.52	16.49	0	22.43	21.67	0.96
52	0	3.32	0	11.07	0	16.61	0	13.84	14.27	0.63
53	0	0	0	4.63	0	0	0	5.79	4.31	0.19
54	0.21	0.83	0	15.32	2.53	4.13	0	19.16	15.31	0.68
55	0	0	0	14.95	0	0	0	18.68	13.21	0.59
56	0	13.61	0.94	38.72	0	68.05	2.35	48.41	43.15	1.91
57	0	5.06	0	20.44	0	25.32	0	25.55	20.66	0.92
58	0	3.48	0	14.71	0	17.42	0	18.38	16.32	0.72
59	0	6.07	0	21.60	0	30.36	0	27.00	21.42	0.95
Grand Total	4.36	106.27	3.30	576.44	52.30	531.37	8.24	720.55	623.70	27.63

Table8-12: Ward-level estimated length and exposure values for bridges

Ward	Bridge	
	Total Length (in KM)	Total Replacement Cost (in crores)
0	15.43	771.35
6	0.05	2.72
9	0.01	0.51
24	0.01	0.63
29	0.02	0.86
31	0.14	7.18
37	0.90	45.16
38	0.82	41.12
40	0.12	6.09
45	0.12	5.97
46	0.05	2.72
48	0.28	14.03
49	0.78	38.92
50	0.07	3.53
51	0.81	40.33
52	0.14	7.02
53	0.03	1.63
54	0.01	0.53
56	4.82	241.12
57	0.92	46.02
58	0.28	13.98
59	0.18	9.20
Grand Total	26.01	1,300.63

Table 8-13: Ward-level estimated length and exposure values for wastewater, potable waterlines and communication system

Ward	Total Waste Water Length (in km)	Total Potable Water Length (in km)	Total Replacement Cost of Waste Water (in crore)	Total Replacement Cost of Potable Water (in crore)	Total Count of Landline Connections	Total Count of Mobile Connections	Total Count of Telecommunication Towers	Total Replacement Cost of Landline Connections (in crores)	Total Replacement Cost of Mobile Connections (in crores)	Total Replacement Cost of Telecommunication Towers (in crores)
1	7.32	2.65	3.66	1.33	122	3,732	5	0.06	0.27	1
2	8.7	8.93	4.35	4.46	115	579	3	0.06	0.04	0.6
3	26.89	27.6	13.44	13.8	160	810	4	0.08	0.06	0.8
4	14.66	15.05	7.33	7.52	183	926	5	0.09	0.07	1
5	6.11	5.35	3.05	2.68	55	1,345	2	0.03	0.1	0.4
6	21.23	18.6	10.62	9.3	71	1,729	9	0.03	0.13	1.8
7	5.56	5.19	2.78	2.6	71	1,752	3	0.04	0.13	0.6
8	6.86	7.54	3.43	3.77	72	1,424	4	0.04	0.1	0.8
9	8.26	6.17	4.13	3.08	194	1,509	5	0.1	0.11	1
10	5.31	4.68	2.66	2.34	140	1,984	2	0.07	0.14	0.4
11	9.44	8.07	4.72	4.03	230	2,009	3	0.11	0.15	0.6
12	4.62	3.86	2.31	1.93	205	1,998	2	0.1	0.15	0.4
13	4.58	3.97	2.29	1.98	133	1,604	2	0.07	0.12	0.4
14	5.4	4.23	2.7	2.11	79	1,844	2	0.04	0.13	0.4
15	13.1	11.85	6.55	5.92	190	1,972	7	0.09	0.14	1.4
16	10.21	9.05	5.11	4.53	115	1,417	5	0.06	0.1	1
17	3.41	3.5	1.7	1.75	160	1,372	1	0.08	0.1	0.2
18	4.71	4.22	2.35	2.11	159	1,344	2	0.08	0.1	0.4
19	2.28	1.74	1.14	0.87	79	1,911	1	0.04	0.14	0.2
20	2.88	2.87	1.44	1.44	29	658	1	0.01	0.05	0.2

Ward	Total Waste Water Length (in km)	Total Potable Water Length (in km)	Total Replacement Cost of Waste Water (in crore)	Total Replacement Cost of Potable Water (in crore)	Total Count of Landline Connections	Total Count of Mobile Connections	Total Count of Telecommunication Towers	Total Replacement Cost of Landline Connections (in crores)	Total Replacement Cost of Mobile Connections (in crores)	Total Replacement Cost of Telecommunication Towers (in crores)
21	3.98	3.71	1.99	1.86	192	882	1	0.1	0.06	0.2
22	4.05	4	2.02	2	127	1,645	2	0.06	0.12	0.4
23	2.23	1.98	1.11	0.99	103	969	1	0.05	0.07	0.2
24	2.39	2.19	1.19	1.09	47	981	1	0.02	0.07	0.2
25	7.07	6.28	3.53	3.14	161	2,039	2	0.08	0.15	0.4
26	2.05	1.9	1.02	0.95	96	2,644	1	0.05	0.19	0.2
27	3.52	3.23	1.76	1.61	71	1,472	1	0.04	0.11	0.2
28	5.96	5.14	2.98	2.57	172	1,416	2	0.09	0.1	0.4
29	5.75	5.15	2.88	2.57	79	1,858	2	0.04	0.14	0.4
30	3.49	3.12	1.74	1.56	149	1,395	1	0.07	0.1	0.2
31	6.18	5.65	3.09	2.82	104	1,757	3	0.05	0.13	0.6
32	5.04	4.65	2.52	2.33	95	1,549	2	0.05	0.11	0.4
33	3.2	3.17	1.6	1.59	259	1,536	2	0.13	0.11	0.4
34	3.19	2.71	1.6	1.36	118	1,692	2	0.06	0.12	0.4
35	9.59	8.5	4.79	4.25	108	1,334	4	0.05	0.1	0.8
36	4.65	4.45	2.33	2.23	186	1,275	2	0.09	0.09	0.4
37	8.91	8.63	4.45	4.32	94	1,662	5	0.05	0.12	1
38	9.4	5.16	4.7	2.58	52	1,007	4	0.03	0.07	0.8
39	6	5.48	3	2.74	49	1,446	2	0.02	0.11	0.4
40	5.4	5.38	2.7	2.69	61	1,100	3	0.03	0.08	0.6
41	3.63	3.7	1.81	1.85	74	1,725	2	0.04	0.13	0.4
42	10.07	9.2	5.04	4.6	62	1,649	4	0.03	0.12	0.8

Ward	Total Waste Water Length (in km)	Total Potable Water Length (in km)	Total Replacement Cost of Waste Water (in crore)	Total Replacement Cost of Potable Water (in crore)	Total Count of Landline Connections	Total Count of Mobile Connections	Total Count of Telecommunication Towers	Total Replacement Cost of Landline Connections (in crores)	Total Replacement Cost of Mobile Connections (in crores)	Total Replacement Cost of Telecommunication Towers (in crores)
43	11.47	11.54	5.73	5.77	93	1,498	5	0.05	0.11	1
44	8.47	7.88	4.23	3.94	95	1,623	3	0.05	0.12	0.6
45	5.96	5.82	2.98	2.91	85	1,626	4	0.04	0.12	0.8
46	6.42	6.01	3.21	3	86	1,763	5	0.04	0.13	1
47	19.61	19.29	9.81	9.64	293	2,197	5	0.15	0.16	1
48	7.99	3.25	4	1.63	92	1,858	3	0.05	0.14	0.6
49	18.15	7.34	9.08	3.67	76	1,981	7	0.04	0.14	1.4
50	16.3	21.13	8.15	10.56	92	2,350	12	0.05	0.17	2.4
51	7.99	11.37	4	5.68	61	1,858	3	0.03	0.14	0.6
52	13.66	10.75	6.83	5.37	244	2,031	5	0.12	0.15	1
53	3.14	3.62	1.57	1.81	133	1,458	3	0.07	0.11	0.6
54	7.07	7.41	3.53	3.71	136	1,593	7	0.07	0.12	1.4
55	7.97	1.72	3.98	0.86	55	1,566	4	0.03	0.11	0.8
56	8.47	3.3	4.24	1.65	78	1,651	10	0.04	0.12	2
57	4.06	1.58	2.03	0.79	63	1,333	7	0.03	0.1	1.4
58	3.87	1.27	1.94	0.64	32	684	6	0.02	0.05	1.2
59	6.78	0.77	3.39	0.39	64	861	8	0.03	0.06	1.6
Grand Total	444.66	382.54	222.33	191.27	6,795	92,885	214	3.37	6.78	42.8

8.7 Annexure 4: Cyclonic Wind Risk Assessment Maps

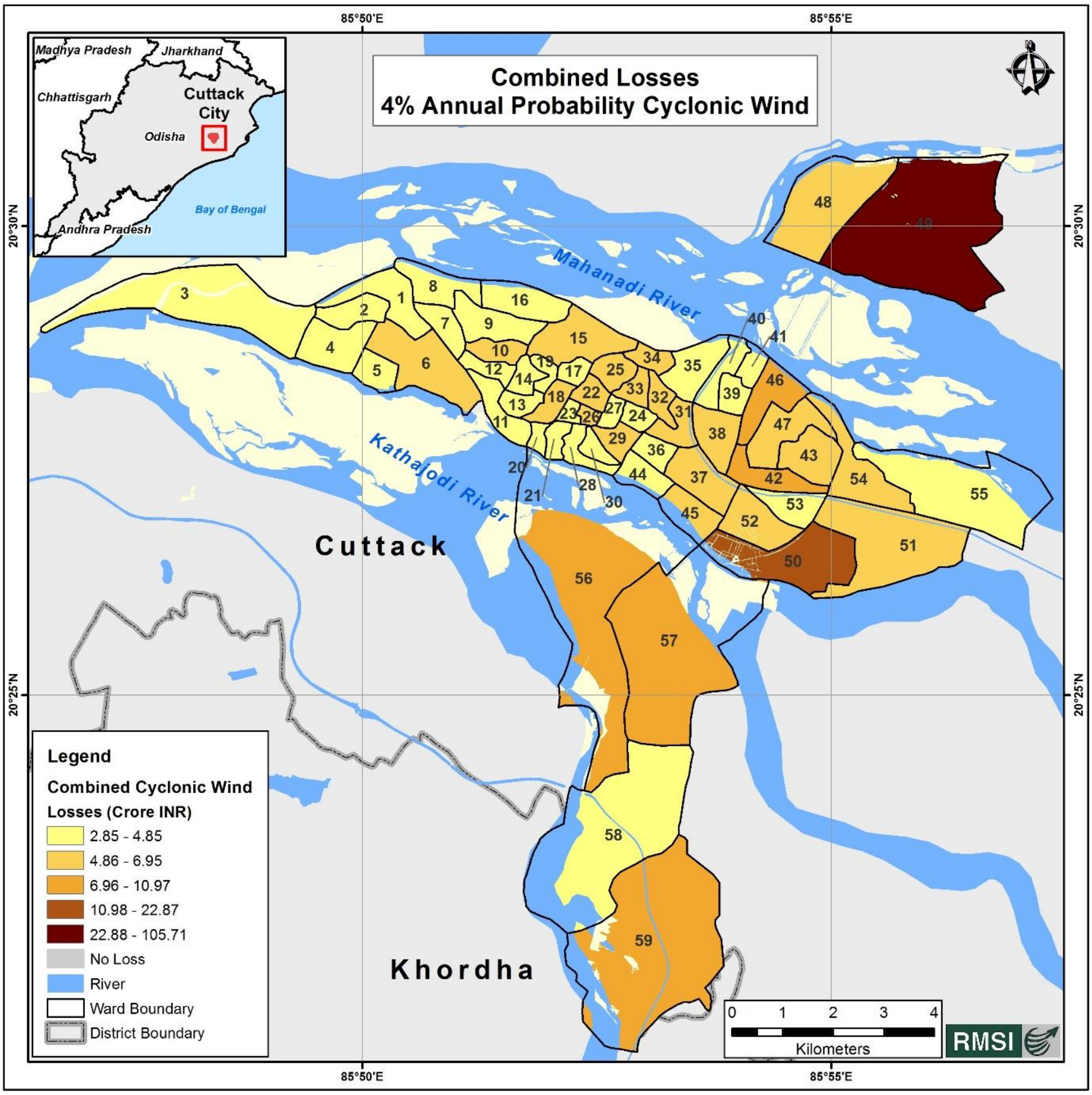

Figure 8-40: Ward wise distribution of estimated combined potential losses for 4% annual probability cyclonic wind

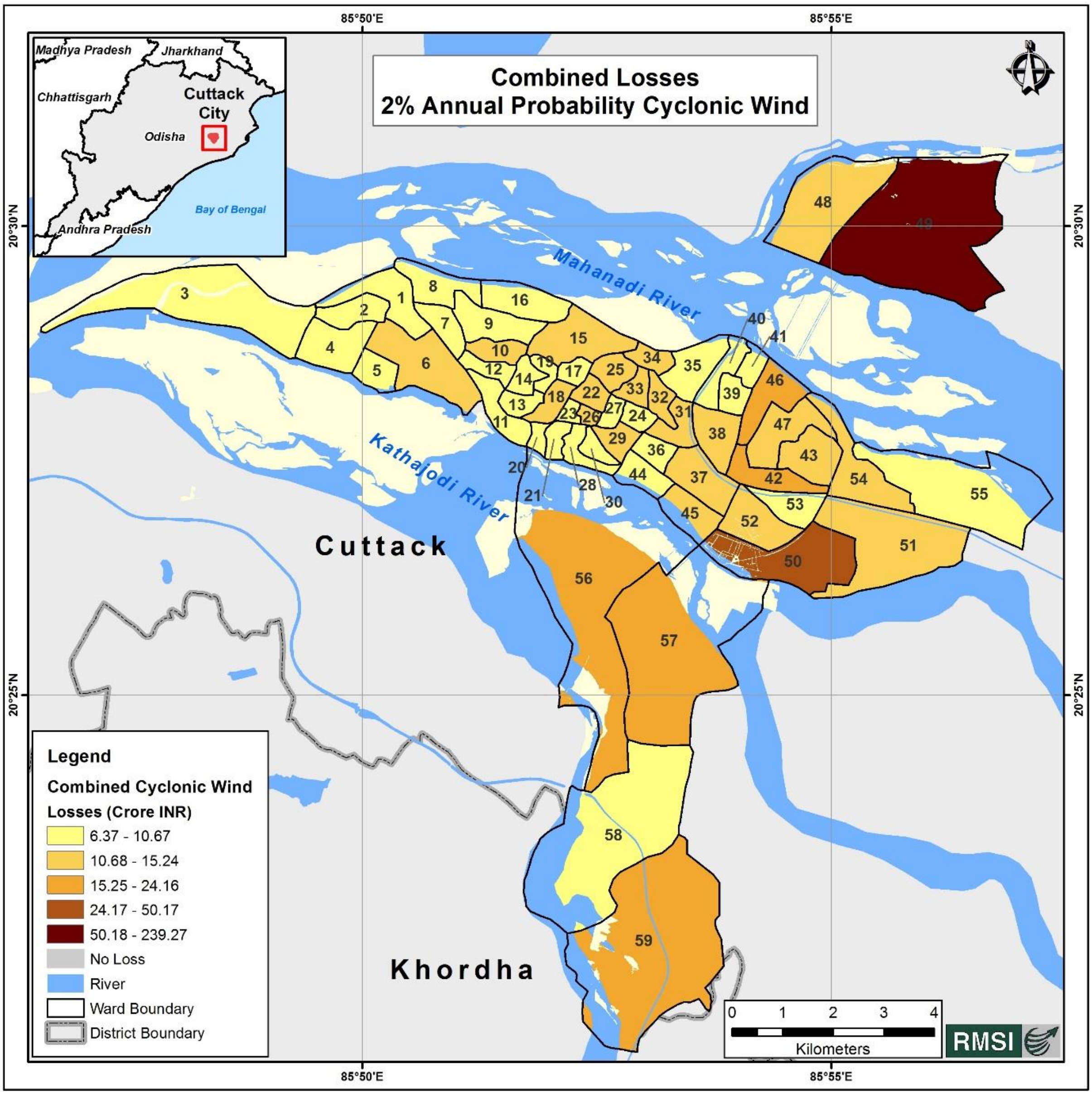

Figure 8-41: Ward wise distribution of estimated combined potential losses for 2% annual probability cyclonic wind

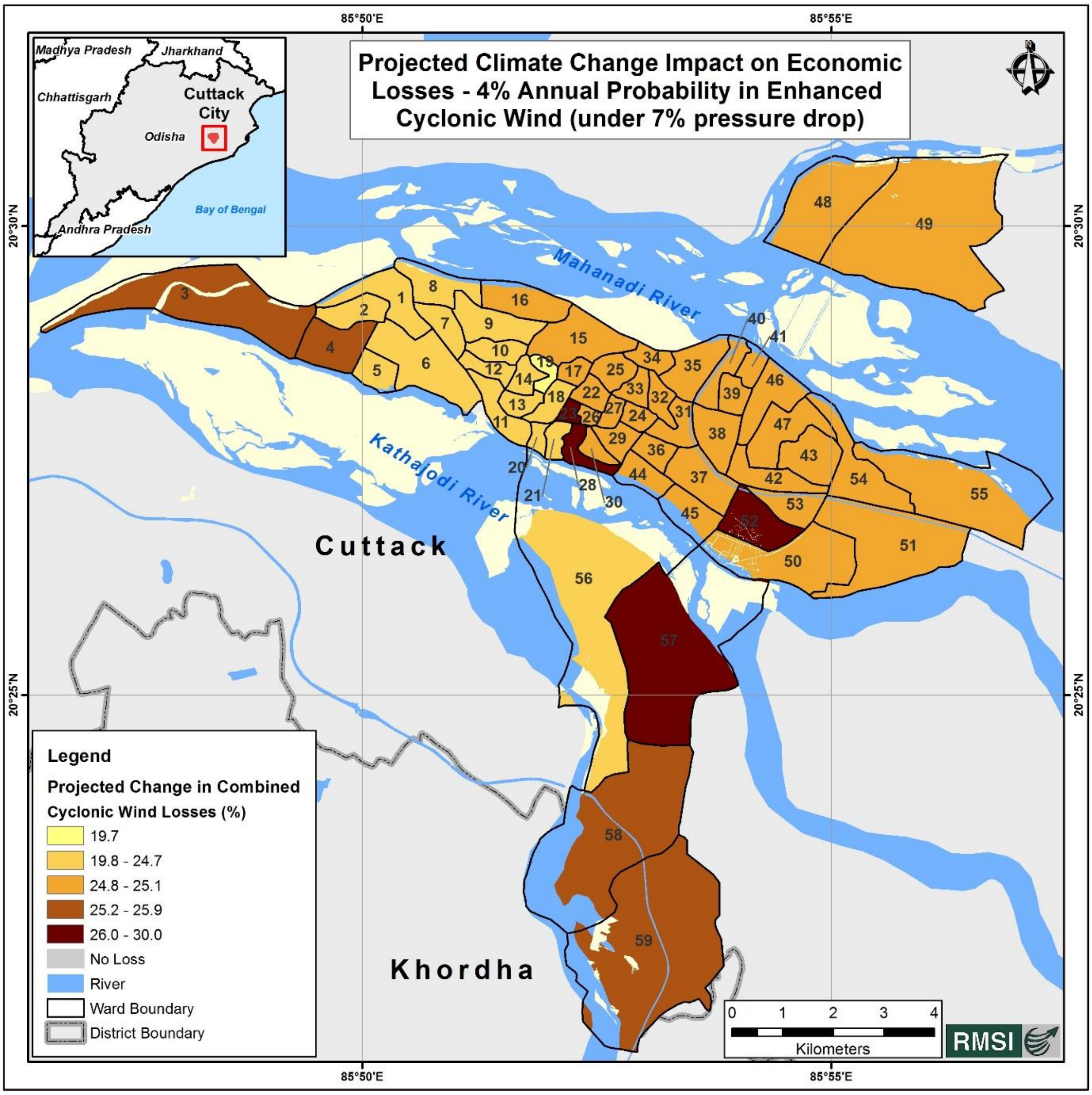

Figure 8-42: Ward wise estimated change in losses due to climate change impact (7%) on 4% annual probability cyclonic wind

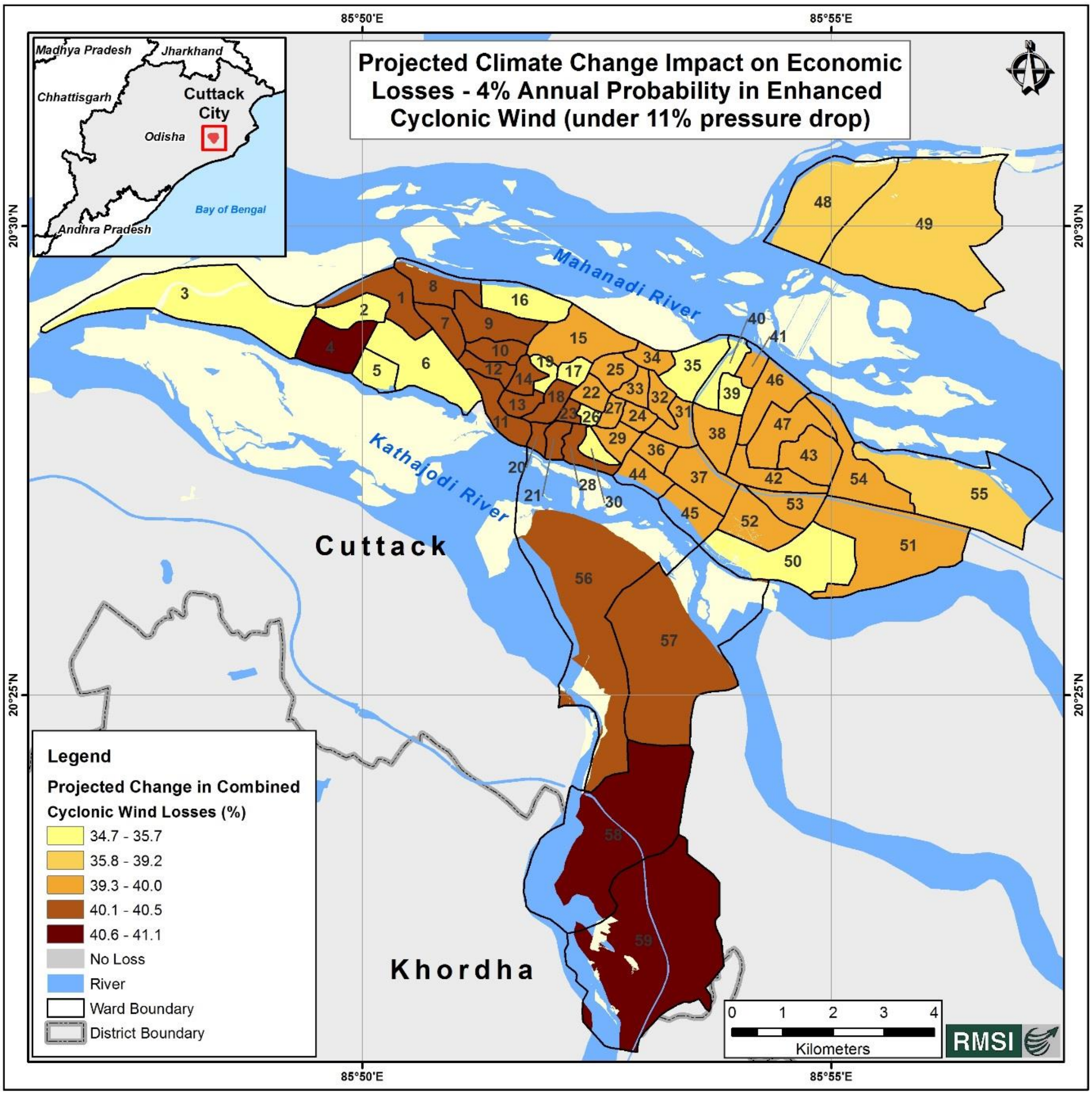

Figure 8-43: Ward wise estimated change in losses due to climate change impact (11%) on 4% annual probability cyclonic wind

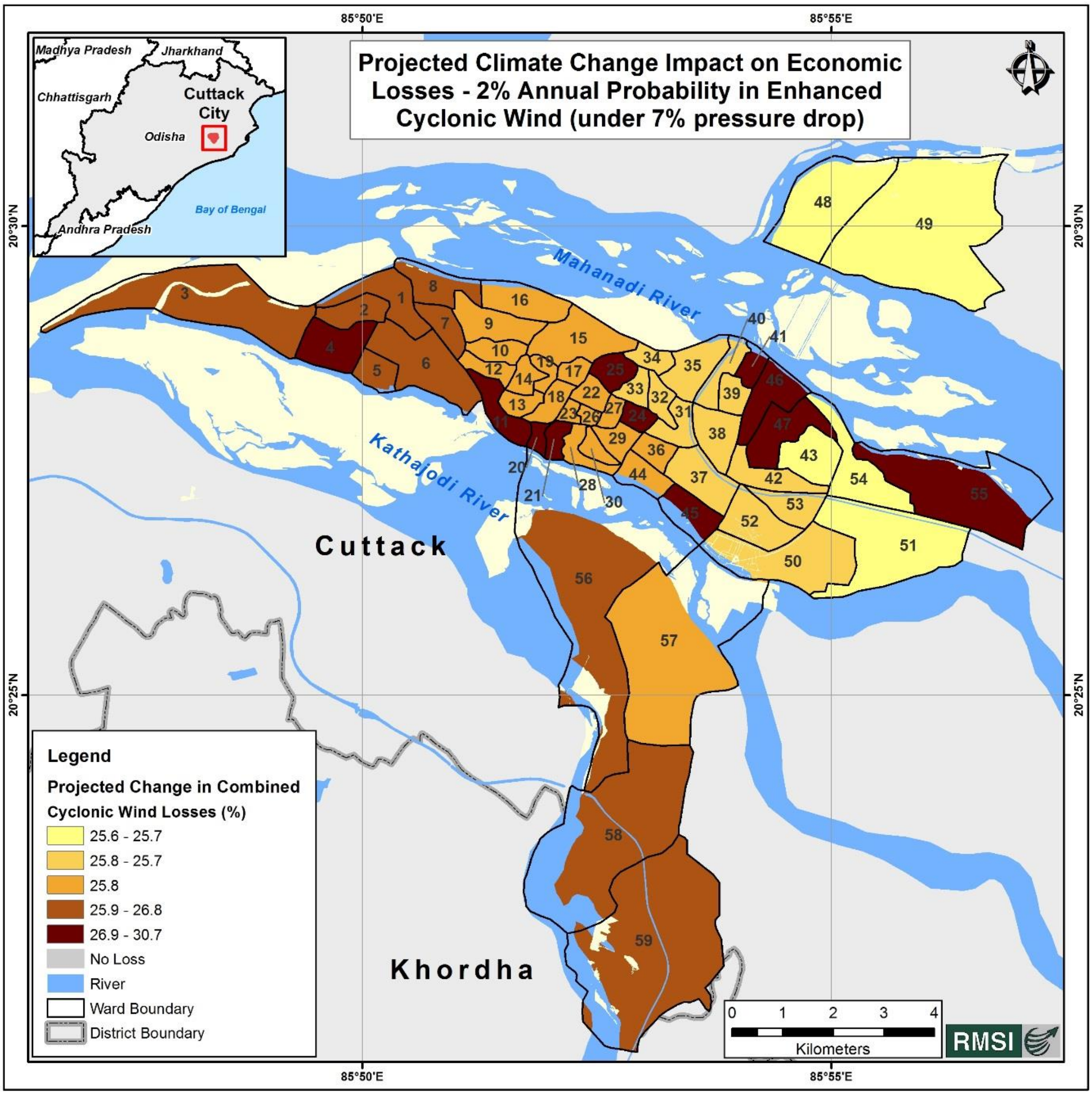

Figure 8-44: Ward wise estimated change in losses due to climate change impact (7%) on 2% annual probability cyclonic wind

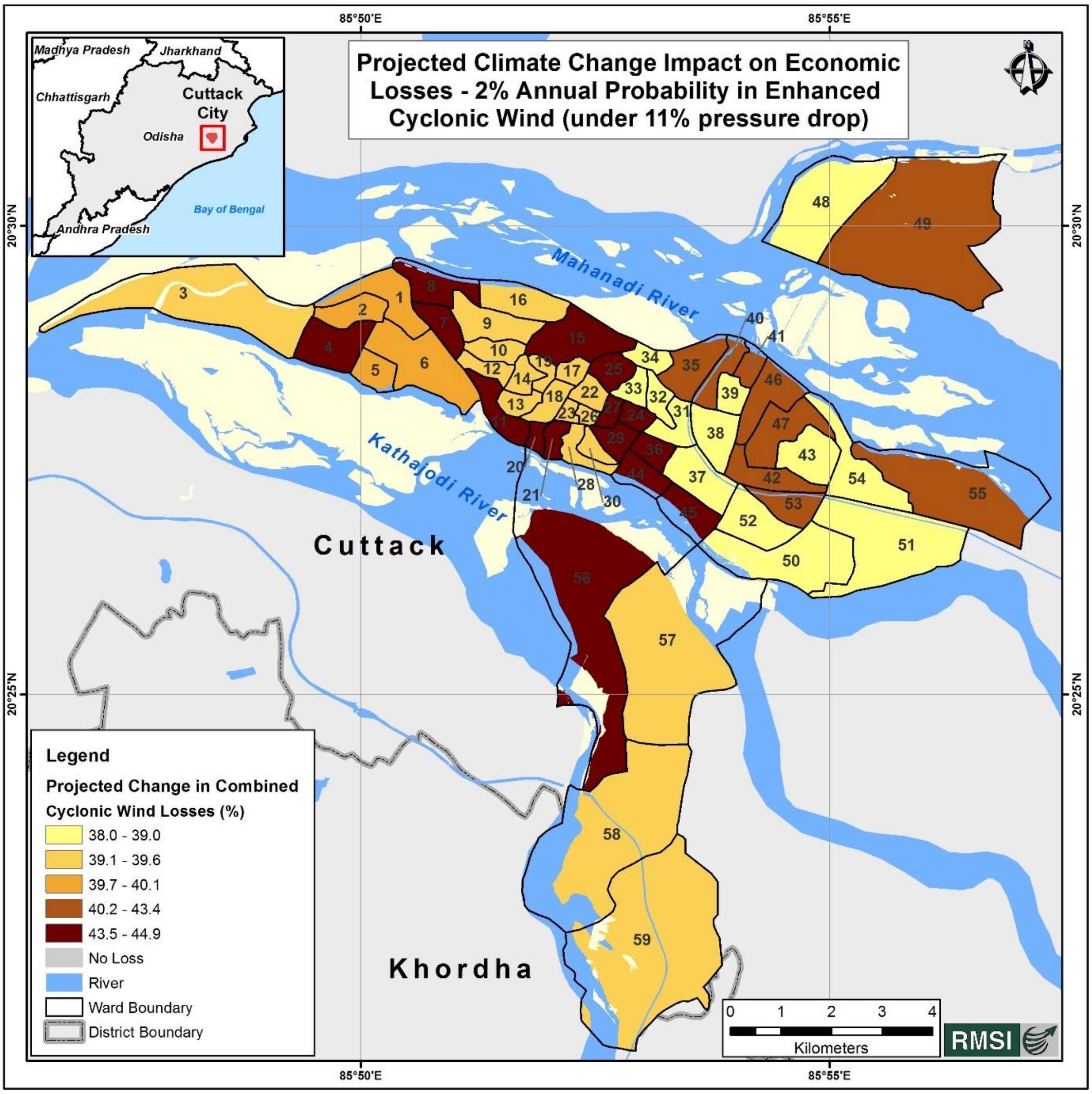

Figure 8-45: Ward wise estimated change in losses due to climate change impact (11%) on 2% annual probability cyclonic wind

8.8 Annexure 5: Flood Risk Assessment Data and Maps

The return period is chosen by the designer, in consultation with the owner, following established hydrologic practice. An assessment of risk is paramount to the selection of return period. Table 8-14 may be used as a guideline, when used in conjunction with local regulations and experience.

Table 8-14: Guidelines for the selection of return period

No.	Type of project or feature	Return period (yr)
1	Urban drainage [low risk] (up to 100 ha)	5 to 10
2	Urban drainage [medium risk] (more than 100 ha)	25 to 50
3.	Road drainage	25 to 50
4	Principal spillways (dams)	25 to 100
5	Highway drainage	50 to 100
6	Levees [medium risk]	50 to 100
7	Urban drainage [high risk] (more than 1,000 ha)	50 to 100
8	Flood plain development	100
9	Bridge design (piers)	100 to 500
10	Levees [high risk]	200 to 1000
11	Emergency spillways (dams)	100 to 10,000 (PMP)
12	Freeboard hydrograph [for a class (c) dam]	10,000 (PMP)

Source: Ponce, V.M. Q & A on the return period to be used for design. Sourced 20 May 2016. http://returnperiod.sdsu.edu/

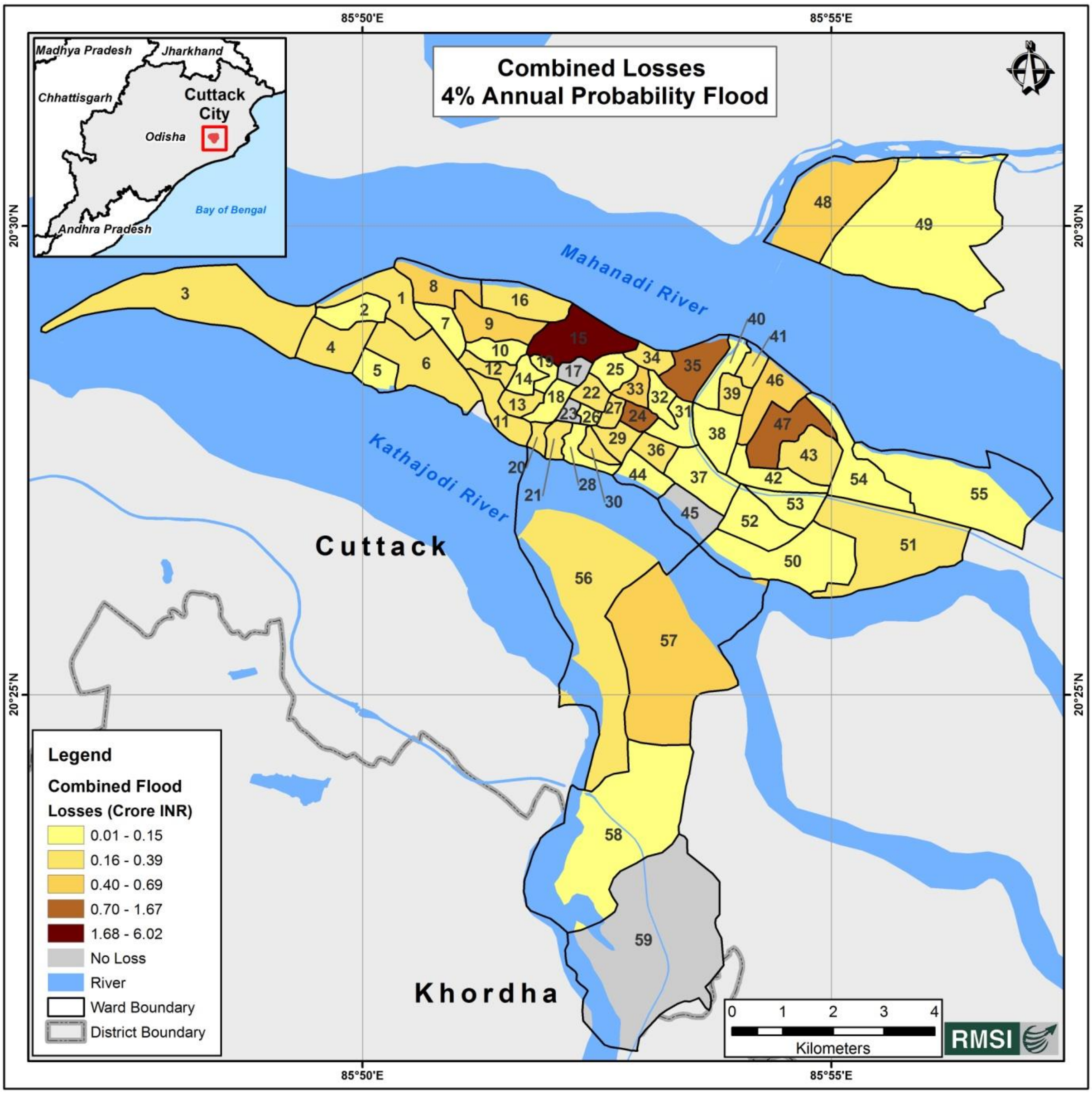

Figure 8-46: Ward-level distribution of estimated combined potential losses due to for 4% annual probability flood

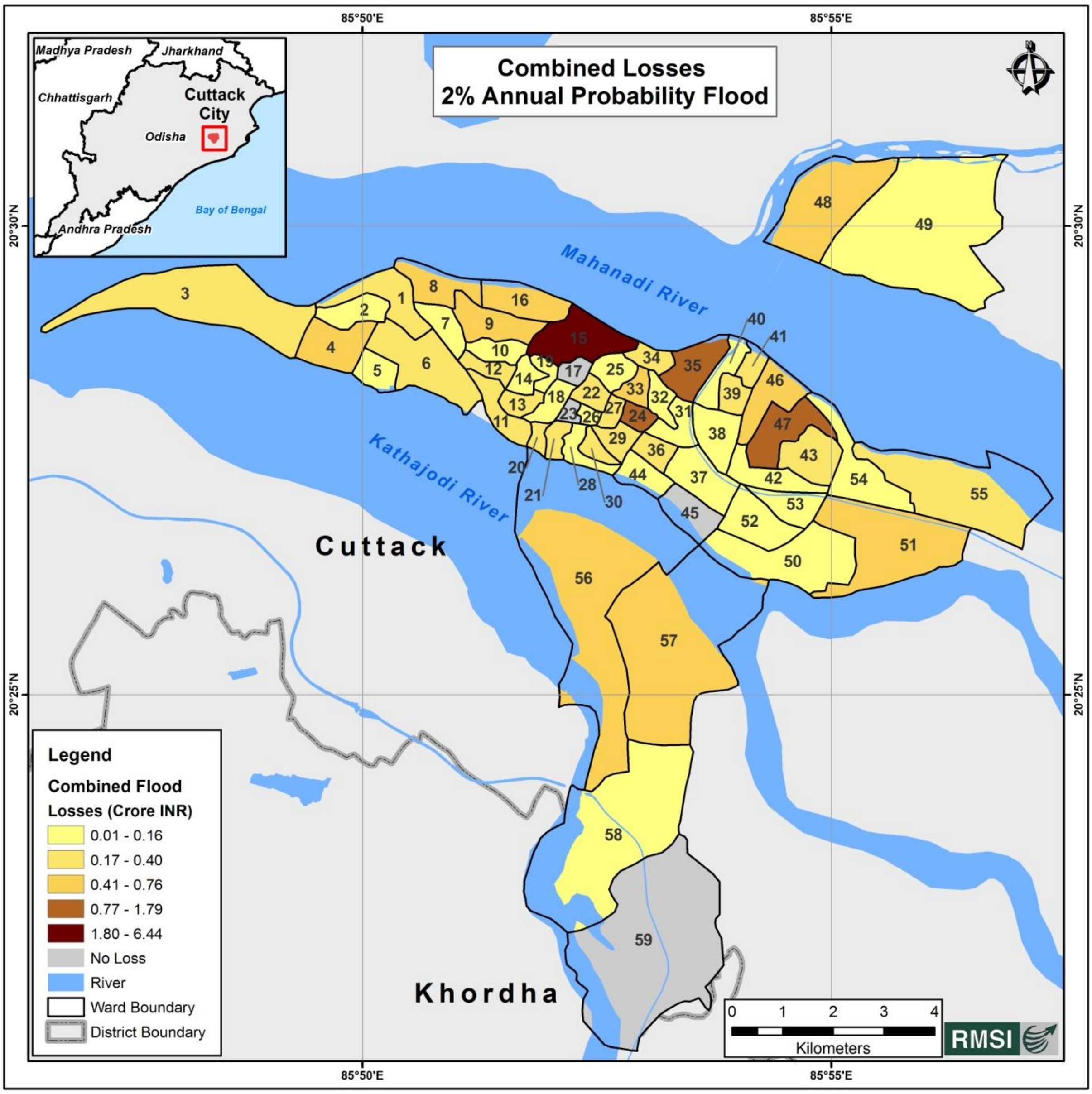

Figure 8-47: Ward-level distribution of estimated combined potential losses due to for 2% annual probability flood

8.9 Annexure 6: Survey Questionnaires

8.9.1 RVS Survey Forms

Rapid Visual Survey for Masonry Buildings (For Earthquake Safety)

Buildin g type	Brick Masonry	Stone Masonry	Compos ite			SEISMIC ZONE
Buildi ng use	Residen tial	Comme rcial	Indust rial	Office	Residential + Comm.	Others:
Address and location/Street					City:	Full access
					Ward no.	Partial access
					Pin code:	No access

Year of construction	Age of building	Number of floors (specify G, G+1, G+2...):

Checklist of Observables	Comments
Structural irregularities	
Availability of walls in both orthogonal directions	Yes/No
Heavy over hanging	Yes/No
Reentrant Corners	Yes/No
Corner buildings	Yes/No
Apparent Quality	
Apparent quality of materials and construction	Good/Moderate/Poor
Maintenance	Good/Moderate/Poor
Short column	Yes/No
Pounding	
Contiguous buildings	Yes/No
Poor apparent quality of adjacent building	Yes/No
Opening	
Large opening in walls	Yes/No
Irregularly placed openings	Yes/No
Openings at corner of bearing wall intersections	Yes/No
Diaphragm Action	
Evidence of absence of Diaphragm	Yes/No
Evidence of large cut outs in Diaphragm	Yes/No
Other features	
Horizontal bands at Plinth Level	Yes/No
Horizontal bands at lintel Level	Yes/No
Horizontal bands at still Level	Yes/No
Horizontal bands at roof Level	Yes/No
Arches present/absent	Yes/No
Jack Arch roof	Yes/No
Stone/masonry chimneys	Yes/No
Random rubble stone masonry walls	
Presence of thick walls 600mm and above	Yes/No
Use of rounded stones	Yes/No
Heavy roofs on DRRM walls	Yes/No
Falling Hazards Non-structural elements such as elaborate parapets, AC unit grilles, elevation features, advertisement hoarding, roof signs, marquees, etc.	Yes/No
Wall Thickness at Ground Floor	
External	
Internal	
Water tank at roof	
Capacity (approx. in litres)	
Location – Symmetrically Placed or not	Yes/No
Basement- Full or Partial	

PICTURES/SKETCHES	

			CALCULATION SHEET MANSONRY	
Falling Hazard Identifier 'F'			**Seismic Zone**	**Base score**
Marquees/Hoardings/ Roof Signs	Yes/No	Stories	III	
AC Units/Grill work	Yes/No	G or G+1		150
Elaborate parapets	Yes/No	G+ 2		125
Heavy elevation features	Yes/No	G+3		110
Heavy Canopies	Yes/No	G+4		70
Substantial Balconies	Yes/No			
Heavy Cladding	Yes/No			
Structural Glazing	Yes/No			

Number of storeys	1 or 2	3	4	5	Vulnerability Score Modifiers	
Vulnerability Scores *(VS)*					(VSM)	(VS X
Structural irregularity	-10	-10	-10	-10	Doesn't exist=0 Exists=1	
Apparent Quality	-10	-10	-10	-10	Good=0 Moderate=1 Poor=2	
Soil Conditions	10	10	10	10	Medium=0 Hard=1 Soft=-1	
Pounding	0	-3	-5	-5	Doesn't exist=0 Normal apparent condition of adjacent building =1 Poor apparent condition of adjacent building =2	
Openings						
Wall openings	-5	-5	-5	-5	Small (less than 1/3)=0 Moderate (between 1/3 and 2/3)=1 Large (above 2/3)=2	
Orientation of openings	-2	-5	-5	-5	Regular=0 Irregular=1	
Diaphragm Action	-10	-15	-15	-15	Present/unsure=0 Lack of diaphragm action= 1	
Other features						
Horizontal bands	20	20	20	20	Exist=1 Don't exist=0	
Arches	-10	-10	-10	-10	Exist=1 Don't exist/unsure=0	
Brick/Stone Mansonry						
Brick/Random rubble stone Mansonry walls	-15	-15	-15	-15	Remedial measures exist=0 Don't exist=1	
Water tank at roof capacity	0	-3	-4	-5	Don't exist=0 Capacity <5000 litre=-0.5 Capacity >5000 litre=1	
Location of the water tank	0	-3	-4	-5	Symmetric=0 Unsymmetric=1	
Basement – full or partial	0	3	4	5	Don't exist=0 Exist=1	
					$\sum$[(VSM) x (VS)]	

Performance Score = (BS)+ $\sum$[(VSM) x (VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual	**Performance Score**

Rapid Visual Survey for R.C.C. Framed Buildings (For Earthquake Safety)						
Building type	RC Frame					SEISMIC ZONE
Building use	Residential	Commercial	Industrial	Office	Residential+ Comm.	Others:
Address and location/Street					City:	Full access
					Ward no.	Partial access
					Pin code:	No access
Year of construction			Age of building		Number of floors (specify G, G+1, G+2…):	
Checklist of Observables					Comments	
Soft storey Open parking at ground level					Yes/No	
Absence of partition walls in ground or any intermediate storey for shops or other commercial use					Yes/No	
Taller heights In ground or any other Intermediate storey					Yes/No	
Vertical irregularities Presence of setbacks					Yes/No	
Building on sloppy ground					Yes/No	
Plan irregularities Irregular plan. configuration					Yes/No	
Reentrant comers					Yes/No	
Heavy overhangs Moderate horizontal projections					Yes/No	
Substantial horizontal projections					Yes/No	
Apparent Quality Apparent quality of materials and construction					Good/Moderate/Poor	
Maintenance					Good/Moderate/Poor	
Short column					Yes/No	
Size of Columns at Ground GF						
Pounding					Yes/No	
Soil Condition					Hard/Moderate/Soft	
Frame Action					Yes/No Define:	
Falling Hazards Non-structural elements 'Such as elaborate parapets, AC unit grilles, elevation features						
Water tank at roof Capacity (approx. in litres)						
Location – Symmetrically Placed or not					Yes/No	
Basement- Full or Partial						
PICTURES/SKETCHES						

Form 1-B: Performa for Reinforced Concrete Buildings

RVS OF BUILDINGS FOR EARTHOUAKE SAFETY			CALCULATION SHEET RC FRAME	
Falling Hazard Identifier 'F'			**Seismic Zone**	**Base score**
Marquees/Hoardings/ Roof Signs		Stories	III	
AC Units/Grill work		G or G+1		150
Elaborate parapets		G+ 2		140
Heavy elevation features		G+3		120
Heavy Canopies		G+4		100
Substantial Balconies		>G+4		90
Heavy Cladding				
Structural Glazing				

Number of storeys	1 or 2	3	4	5	>5	Vulnerability Score Modifiers	
Vulnerability Scores *(VS)*						(VSM)	(VS X VSM)
Soft Story	0	-15	-20	-25	-30	Doesn't exist=0 Exists=1	
Vertical irregularities Setbacks Buildings on Slopes	-10	-10	-10	-10	-10	Doesn't exist=0 Exists=1	
Plan irregularities	-5	-5	-5	-5	-5	None=0 Moderate=l Extreme=2	
Heavy Overhangs	-5	-10	-10	-15	-15	Doesn't exist=0 Exists=1	
Apparent quality	-5	-10	-10	-15	-15	Good=0 Moderate=1 Poor=2	
Short columns	-5	-5	-5	-5	-5	Doesn't exist=0 Exists=l	
Pounding	0	-2	-3	-3	-3	Doesn't exist=0 Unaligned floors=2 Poor apparent quality of adjacent Building=2	
Soil Condition	10	10	10	10	10	Medium=0 Hard=1 Soft= - 1	
Frame Action	10	10	10	10	10	Doesn't exist= - 1 Exists= 1 Not sure= 0	
Water tank at roof capacity	0	-3	-4	-5	-5	Doesn't exist = 0 Capacity < 5000 lit = 0.5 Capacity > 5000 lit = 1	
Location of water tank	0	-3	-4	-5	-5	Symmetric = 0 Unsymmetrical =1	
Basement - Full or Partial	0	3	4	5	5	Doesn't exist = 0 Exist = l	
						$\sum[(VSM) \times (VS)]$	

Performance Score = (BS)+$\sum[(VSM) \times (VS)]$ where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual	**Performance Score**

8.9.2 SOCIAL VULNERABILITY SURVEY FORMS

HRVA study of Cuttack Municipal Corporation

Questionnaire for Household Profile for Social Vulnerability Analysis

Note for the Surveyors: If there are multiple options, please tick the applicable ones. In case any of the questions are not relevant to the area of the Household (HH) please write "NA". Question A and B should be filled by surveyors on their own through observation.

Basic details

A1. Form No.	A2. Ward no.	A3. Ward name:
A4. Surveyors name		A5. Date of survey
A6. Location details: (provide the house location details like at hill slope, or river bank, or in heavily populated area, etc.)		

House location and structural information

B1. Structural details

(a) Roof material: grass/hay/thatch, plastic sheet, tile, tin sheet, asbestos, concrete

(b) Wall material: grass/hay/thatch, plastic sheet, mud, brick, wood, concrete

(c) Floor material: mud, brick, wood, concrete

B2. House characteristics

(a) Number of rooms:
(b) Age of the house:
(c) Plinth height (provide in feet):

B3. House is located:

(a) Own land (private), (b) government allotted land, (c) public land (not allotted but occupied and living)

B4. House ownership history:

House hold information

C1. Name of respondent:	C2. Position in the house:

C3. Number of member males:	C4. Number of member females:
C5a. No. of people age < 6 C5b. No. of people age >60:	C6. No. of differently enabled members:
C7. House ownership: (a) own, (b) rented, (c) ancestral, (d) others	C8. How long your family is living in this house: (a) <1 yr, (b) 1-5 yrs, (c) > 5 yrs
C9. Source of income for the family member (choose all that are applicable): (a) Government job, (b) domestic worker, (c) working in factory, (d) trader/shop (e) traditional handicraft (f) vendor, (g) casual worker, (h) agriculture, (i) fishing, (j) no job, (k) others specify:	C10. Monthly family income: (a) <2000, (b) 2001-5000, (c) 5001-10,000, (d) >10,000 C11. Number of earning members:

3. Household Assets

***3.1** Please indicate which of the following assets you own [Enumerator: Use questions and observation. Mention quantity applicable. If not available mark 'x'. Do not leave any blanks. Add any other item mention]*

Asset	Number	**Asset**	Number	**Asset**	Number	**Asset**	Number
Flush toilet		Bicycle		Handpump		Cattle	
Pit Latrine		Motorbike		Dug well		Buffalo	
Toilet municipality		Car/truck				Goat	
TV		Tractor		Money on bank		Poultry	
Landline		Ox cart		Jewelry		Pigs	
Mobile		Boat		Capital lend out			
Fridge		Fishing net					
Airco							

4.1 Details of access to public/ service facilities:

	Y	N		Y	N
Do you have at your home:			**If you need, can you make use of:**		
Piped water supply (in house)			Micro-credit facilities		
Private well			Credit from money lender		
Electricity from grid			Credit from bank		
Electricity from communal generator			LP school (mention distance)		
Electricity from private generator			UP school (mention distance)		
			Other school:(mention distance)		
Do you have access to:			Doctor (mention distance)		
Community tap					
Community well					

Other water source (rain, river, pond)					
Public latrine					

C12. Why did you choose this location for living:

(a) Relocated by government from a hazard affected area, (b) Relocated by government as part of area development, (c) came here looking for job/livelihood, (d) since this was vacant land just constructed the house and living (d) ancestral property, (e) others specify:

A. Disease history

Year (provide for each year. In case there are two events in one year provide that separately)	Disease (Malaria, chinkangunea, gastritis, jaundice diarrhea)	When (after flood, during heat wave, during heavy rain, others specify)	Number of people affected in your family	Any death

B. Hazard history

Living in this house/locality have you ever affected by any natural hazards? Flood, wind, heat stroke, earthquake, others, please specify

Year (provide for each year. In case there are two events in one year provide that separately)	Hazard type (any natural hazard specify the name Flood, Cyclone, Heat stroke, *Earthquake*	Nature of damage ((a) House completely collapsed, (b) roof destroyed, (c) assets in the house destroyed but house not damaged, (d) life loss, (e) animal life loss, (f) agriculture loss)	Damage in Rupees (Approximate damage for each item mentioned in the column 3 separately)

C. Flood and cyclone (Hazard) early warning:

F1. How you assess the natural disaster risk in the area you are living: high, medium, low, no risk

F2. Which is the worse hazard you faced living in this locality (event and year)?

F3. What precaution you have taken to prevent/reduce the risk?

F4. Are you aware of early warning systems, which can help in reducing the impact of a hazard: Yes/No

F5. Is there any mechanism by government/local bodies/private, on providing early warning of a hazard: Yes/No

F6. If Yes what kind of mechanism available: (a) inform through announcement (public address system) (b) radio, (c) TV, (d) newspaper, (e) other specify:

D. Preparedness and Mitigation

G1. Did you face any difficulty (disaster risk) in living in this location:

G1. What mechanism you have devised to protect your asset and house from natural hazards?

G2. What mechanism government/city administration has devised to protect your house from natural hazards?

G3. Do you have an insurance against natural hazards?

G4. Do you have any community initiatives to protect the communities from natural hazards?

G5. According to you what need to be done to reduce the impact of natural hazard to your locality?

E. Relief and recovery

H1. Have you ever been given help with disaster relief? Yes/No

H2. If Yes, describe when, by whom and nature of help given:

H3. Was this help adequate? Yes/No

H4. If not, why?

H5. How you managed to get back to life after affected by natural hazard: (a) Government support, (b) own money, (c) borrowed, (d) took loan, (e) others specify

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