Kerala State Disaster Risk Financing Strategy

COMPONENT 1: HAZARD RISK, ECONOMIC AND FINANCIAL LOSS DATABASE OF MAJOR DISASTERS

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Prepared and Submitted By
RMSI Private Limited, India

Head Office: A-8 Sector 16, Noida 201 301, India
Tel: +91 120 251 1102, 251 2101
Fax: +91 120 251 1109, 251 0963
www.rmsi.com

In association with
NATIONAL INSURANCE ACADEMY

For the attention of:

Chief Executive Officer, Rebuild Kerala Initiative, Planning & Economic Affairs (RKI) Department, Government of Kerala, 1A, CALSAR Heather Tower, Punnen Road, Near Government Secretariat, Thiruvananthapuram Email: rkisecretariat@kerla.gov.in	
Contact: **Dr. Sushil Gupta**, Project Team Leader and Vice President, Risk Modeling and Insurance, Sustainability Email: sushil.gupta@rmsi.com	
Company Information:	
Name	RMSI Private Limited
CIN	U74899DL1992PTC047149
Registered Office Address	50/9, 1st Floor, Tolstoy Lane, Janpath, New Delhi, India – 110001
Corporate Office Address	A-8, Sector-16 NOIDA, 201 301 India Tel: +91 120 251 1102, 251 2101 Fax: +91 120 251 1109, 251 0963 E-mail: info@rmsi.com

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Executive Summary

This study addresses the critical need for comprehensive disaster management and risk reduction strategies in Kerala, a state significantly impacted by natural disasters over the past three decades. The primary aim is to develop detailed databases of historical hazard events and their economic impacts, conduct risk assessments, and propose financial mechanisms to enhance resilience and preparedness for future disasters.

Natural disasters such as floods, landslides, cyclones, storm surges, and droughts have caused substantial economic losses and human suffering in Kerala. The State is also vulnerable to coastal hazards (erosion and sea level rise), forest fires, earthquakes, tsunami, soil-piping, and lighting and thunderstorms.

The study seeks to compile a comprehensive database of major historical hazard events in Kerala, document the economic and financial losses resulting from these disasters, conduct hazard, vulnerability, and risk assessments, develop a state disaster risk financing strategy, and establish methodologies for prototype parametric risk transfer products to provide timely financial assistance.

The development of comprehensive hazard and financial loss databases, coupled with thorough risk assessments and innovative financial strategies, will position Kerala to better prepare for and respond to natural disasters. By supporting evidence-based decision-making and fostering collaboration among stakeholders, the state can enhance its resilience, reduce vulnerabilities, and safeguard its communities against future disasters. This study emphasizes the importance of proactive measures and strategic investments in building a disaster-resilient community in Kerala state.

In this report, we have developed a consolidated database of major natural disasters in Kerala over the past more than 30 years, including specific details about floods, landslides, cyclones, storm surges, and droughts. This database includes data corresponding the date, location, and physical characteristics of each event, which will help improve the understanding of Kerala's disaster risk profile.

A comprehensive Geo-Referenced Catalogue of historical major disaster events have been developed. Key parameters included in this catalogue are the date, location (latitude and longitude), type of event, its impact areas including damage and losses, project damage and losses, affected economic sectors, and sources of information etc. Quantification of these impacts, helps in identify vulnerabilities and prioritize investments in disaster risk reduction.

This report (Component -1, 2nd deliverable of the study) also dovetails a comprehensive review of hazard, vulnerability and risk assessment of the State. The NatCAT based hazard assessment, exposure development, vulnerability and risk assessment are in the scope of Component -2 Report, and accordingly covered in the Component - 2 Report (3rd deliverable). The Disaster Risk Financing Strategy is covered in the scope of Component -3 Report (4th deliverable) and prototype parametric insurance products are part of Component - 4 Report (5th deliverable).

The following activities were conducted as part of this deliverable:

- *Developed a consolidated database for financial and economic losses from past natural disasters to support probabilistic catastrophic risk models.*
- *Created detailed plots of historical hazards and losses to visualize the*

spatial distribution and impact of past disasters.

- *Compiled a geo-referenced catalogue of historical major hazard events in Kerala using the standardized EM-DAT format.*
- *Prepared a technical report describing data collection methods, limitations, and challenges, addressing issues related to data availability, quality, spatial and temporal resolution, and socio-economic factors*
- *Outlined future directions for enhancing disaster risk management, including recommendations for data improvement, policy development, and advocacy efforts.*

Based on the data gaps and limitations identified in the historical hazard events database, administrative boundaries, building footprints, and demography database, the following recommendations and suggestions are important to improve the quality and availability of data for future updates on hazard and risk assessments:

1. *<u>General:</u> Further, detailed attribute information should be updated in gaps, wherever needed in the current Databases Periodic updation of disaster datasets (preferably yearly or after a major disaster event) as well as yearly updation of exposure database should be carried out as Kerala State is going through rapid development.*
2. *<u>Updation of Building Footprint Database:</u> The housing building footprint database for 5 districts (Ernakulam, Kollam, Kozhikode, Thiruvananthapuram and Kannur) was incomplete and RMSI not only filled this gap but also for rest of State from its in-house database. Building footprint database should be regularly updated at-least once a year as State is witnessing rapid development.*
3. *<u>Updation of Bridges/Flyover Database:</u> The current geospatial database developed by RMSI does not contain name of bridges/ flyover, year of construction, year of major repair etc., and should be updated on priority along with road transport network of the State and then regularly twice a year before (by April) and after end of heavy rains (December).*
4. *<u>Centralized Disaster Database at Event Level:</u> Establish a unified database with detailed spatial, temporal, and disaggregated economic socio-economic loss data at disaster event level (in additional to annual aggregate database) for floods, landslides, cyclones, storm surges, drought and other hazards impacting different parts of Kerala State.*
5. *<u>Regular Updates for Administrative Boundary Data:</u> Ensure at-least once a year updates and validations of Local Self Government (LSG), Towns, Cities, Taluka, Municipality and Municipal Corporations, District and State boundaries, in collaboration with local authorities, KSREC and Survey of India.*
6. *<u>Strengthen Inter-Agency Collaboration:</u> Build a centralized data-sharing platform and foster regular coordination among agencies like KSDMA, KSREC, NRSC, GSI and PWD for data improvements.*

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Abbreviations Used

Abbreviation/Acronym	Expanded form
CMDRF	Chief Minister's Disaster Response Fund
DDMAs	District Disaster Management Authority
DEM	Digital Elevation Models
DRF	Disaster Risk Financing
DRFI	Disaster risk financing and insurance
DTM	Digital Terrain Model
EM-Dat	The International Disaster Database
FIMS	Fisheries Information Management System
FONDEN	Fondo de Desastres Naturales (Natural Disaster Fund)
GIS	Geographic Information System
GSI	Geological Survey of India
IMD	India Meteorological Department
ISRO	Indian Space Research Organization
KSDMA	Kerala State Disaster Management Authority
KSPB	Kerala State Planning Board
KSREC	Kerala State Remote Sensing and Environment Centre
LSI	Landslide Susceptibility Index
LULC	Land Use Land Cover
NAIC	National Association of Insurance Commissioners
NatCAT	Natural Catastrophic
NDEM	National Database for Emergency Management
NDMA	National Disaster Management Authority
NDMIS	National Disaster Management Information System
NDRF	National Disaster Response or Mitigation Fund
NHO	National Hydrographic Office
NRSA	National Remote Sensing Agency
NRSC	National Remote Sensing Centre
NSRP	Neyman–Scott Rectangular Pulses
OSM	Open Street Map
PCRIC	Pacific Catastrophe Risk Insurance Company
PDSI	Palmer Drought Severity Index
PET	Potential Evapotranspiration
PMJJBY	Pradhan Mantri Jeevan Jyoti Bima Yojana
RKI	Rebuild Kerala Initiative
RP	Return Period
SAC	Space Application Centre
SDMF	State Disaster Risk Management Fund
SDRF	State Disaster Response or Mitigation Fund
SDRMF	State Disaster Risk Mitigation Fund
SMRC	SAARC Meteorological Research Centre
SMS	Surface Modeling System

SPC	Segregated Portfolio Company
SPEI	Standard Precipitation Evapotranspiration Index
SRTM	Shuttle Radar Topography Mission
TCIP	Turkish Catastrophe Insurance Pool
TCRM	Tropical Cyclone Risk Model
USD	United States Dollar

1 Introduction

1 Introduction

1.1 Background

Natural disasters, such as floods, landslides, cyclones, storm surges, and droughts, have brought significant economic and human tolls in Kerala over the past three decades. The State is also vulnerable to coastal hazards (erosion and sea level rise), forest fires, earthquakes, tsunami, soil-piping, and lighting and thunderstorms. Understanding the historical occurrence of these hazards and their financial ramifications are paramount for effective disaster risk reduction strategies.

This study aims to compile comprehensive databases documenting major historical hazard events and the resulting economic losses caused by disasters over the past 30 years in Kerala.

Furthermore, the study endeavors to develop exposure database, and conduct hazard, vulnerability, and risk assessments based on state-of-art NatCAT risk modeling methodology, with the objective of developing Kerala State Catastrophic Risk Profile.

Additionally, it seeks to develop a Kerala State Disaster Risk Financing Strategy and establish a methodology for designing a Prototype for Parametric Risk Transfer Products with a focus on housing sector (residential building) and Government Buildings. These proposed products are intended to mitigate the financial impact of disasters by providing efficient and timely financial assistance to affected communities and stakeholders.

1.2 Objectives

1.2.1 Database of Major Historical Hazard Events

The first objective of this study is to construct a database of major historical hazard events in Kerala, focusing on floods, landslides, cyclones, storm surges, and droughts. Data collection involves reviewing existing records and consolidating information from various sources, including the Emergency Events Database (EM-DAT), National Database for Emergency Management (NDEM), National Disaster Management Information System (NDMIS), other portals, such as Kerala State Disaster Management Authority (KSDMA), Geological Survey of India (GSI), National Remote Sensing Agency (NRSC), Central Water Commission (CWC), India Mereological Department (IMD), published research papers and disaster specific reports. It also involves, identification of the independent reporting/ monitoring agencies for each of the major perils. The information and data regarding the historical events, especially, for the past 30 years has been consolidated and efforts have been made to extent this database for longer duration, wherever possible, for example, for floods, we could extent it to 1924.

The database includes (for each of major historical events) at least the following information: occurrence date (start and end date), location (e.g., latitude and longitude of the storm's eye for tropical cyclones), physical characteristics (e.g., central pressure along the track for tropical cyclones), affected area, damage and loss information including causality, etc. It serves to support and calibrate the probabilistic catastrophic risk models., In a nutshell, we aim to improve our understanding of Kerala State Disaster Risk Profile by documenting the occurrence of these hazards. In this study, as part of Component-1 Report (Deliverable -2), we have developed a comprehensive database of major historical disaster events for Floods, Landslides, Cyclones, Storm Surges, and Droughts.

1.2.1.1 Economic and Financial Loss of Major Disasters

Part of the first objective of this report is to develop a database of Economic and Financial losses caused by major disasters in Kerala over the past 30 years. Key actions include, but not limited to review of damage assessment reports, insurance reports, etc. and develop a consolidated database of financial and economic losses caused by natural disasters.

The economic losses are provided in the local currency (INR) and US$, adjusted from inflation and/or currency exchange rate. Datasets are collected from KSDMA Disaster Memorandums, Post Disaster Need Assessment (PDNA) Reports, Insurance Records, and other relevant sources.

In this study, as part of Component-1 Report (Deliverable -2), we have developed a consolidated database of major natural disasters affecting Kerala over the past 30 years, including specific details about disasters caused by Floods, Landslides, Cyclones, Storm-Surges, and Droughts. This database also includes details on Economic and Financial Losses in addition to their other details discussed above, which helps in improving the understanding of Kerala State Disaster Risk Profile.

Hence, as part of Component-1 Report (Deliverable -2), a comprehensive Geo-Referenced Catalogue of historical major disaster events have been developed. Key parameters included in this catalogue are the date, location (latitude and longitude), type of event, areas impacted including damages and losses, number of deaths, number of injured, project damages and losses, affected economic sectors, and sources of information, etc.

1.2.2 STATE CATASTROPHIC RISK PROFILE

The second objective of this study is to conduct comprehensive hazard assessment, exposure development, vulnerability, and risk assessment for major hazards in Kerala using state-of-art catastrophic risk modeling methodology in order to develop Kerala State Catastrophic Risk Profile. This involves modeling key hazards (floods, landslides, cyclones, storm surges, and droughts), developing exposure database, assessing vulnerability of communities and assets, and evaluating potential risks. This Report (Deliverable -3) caters to this Objective of this study.

1.2.3 DISASTER RISK FINANCING STRATEGY

The third objective of this study is development of Disaster Risk Financing Strategy for Kerala State with a focus on Housing sector and Government Building (Deliverable -4).

1.2.4 DESIGN OF PARAMETRIC INDICES

The fourth objective of this study is the design of parametric indices to be used for financial transactions and design Protype Parametric Risk Transfer Instruments including indemnity and parametric-based catastrophe (property) insurance products (Deliverable -5).

This report (Component -1, 2nd deliverable of the study) also dovetails a comprehensive review of hazard, vulnerability and risk assessment of the State. The NatCAT based hazard, exposure, vulnerability is in the scope of Component -2 Report, and accordingly covered in the Component-2 Report (3rd deliverable). The Disaster Risk Financing Strategy is in the scope of Component -3 Report (4th deliverable) and prototype Parametric insurance products are part of Component -4 Report (5th deliverable).

2

Consolidated Database/ Catalogue of Historical Events

2 Consolidated Database/Catalogue of Historical Events

2.1 Review and Consolidation of Existing Databases

2.1.1 Review of Scientific Studies

Evaluate existing scientific literature on the frequency, severity, and spatial distribution of natural and human disasters such as pandemic in Kerala. Synthesize findings to identify trends, vulnerabilities, and potential areas for further research. Assess the reliability and applicability of available data sources to inform hazard risk analysis.

2.1.1.1 Floods

Increasingly erratic rainfall patterns, possibly due to climate change, have contributed to the frequency and severity of floods in Kerala. Deforestation, unplanned urbanization, and poor land-use practices have further exacerbated the impact of flooding and associated landslides.

Approximately 44 rivers originate from the Western Ghats, with 41 of them flowing into either the backwaters and or the Arabian Sea. These rivers are primarily fed by the monsoon rains and are largely perennial. During the rainy season, they flow with turbulence, and the larger rivers often rise 30 to 40 cm above their danger levels, leading to significant flooding in the midland and coastal areas. The combined water volume of Kerala's rivers is approximately 250,000 million cubic feet, accounting for about 5% of India's total water potential.

The rivers of Kerala have not only shaped the geographical landscape but have also played significant roles in the political and military history of the state. For instance, the floods in the Periyar river in 1341 altered the course of history by blocking the mouth of the Cranganore harbor, rendering it unusable for trade. This event led to the rise of Cochin as a prominent trading center, eventually surpassing Cranganore's importance. Additionally, the floods of 1341 are said to have created the Island of Vaipin, with some sources attributing the commencement of the Puduvaipu era in 1341 to this event.

Moreover, the same river, Periyar, played a crucial role in military affairs. In 1789, floods in the Periyar prevented Tipu Sultan from advancing further south of Alwaye and launching an attack on Travancore. This natural barrier influenced the course of Tipu Sultan's military campaign, highlighting the strategic significance of Kerala's rivers in shaping historical events[1].

In 1924, Kerala experienced unprecedented floods, causing significant loss of life, property, and crops. The heavy rainfall, triggered by the south-west monsoon, affected the entire region from July 16 - 18, 1924. Devikulam town in Kerala recorded 484 mm of rainfall in a single day (24 hours), while Munnar recorded 897 mm rainfall over three days (72 hours), highlighting the severity of the event[2]. The extent of paddy crops lost was roughly estimated to be 30,000 acres as shown in Figure 9-1. The memory of the devastating floods of 1924 was lingering in the minds of many Kerala's residents when, in 1961, the state faced another incidence of heavy rainfall and flooding.

Unlike typical monsoon seasons, where heavy precipitation occurs over 7 to 10 days, the floods of 1961 were unusually prolonged and intense. The monsoon season began fiercely in late June, with torrential rains persisting until early August, primarily impacting the southern region and gradually spreading across the entire state by July's second week. In 1961, the Periyar

[1] Padmanabhan, N. (2013). History of Kerala i. New writing, 164, 194.

[2] http://cwc. gov. in/main/downloads/KeralaFloodReport/Rev-1. pdf.

sub-basin bore the brunt of the deluge, affecting other sub-basins as well. Critical infrastructure, including major and minor roads, succumbed to the rising waters. As the monsoon intensified further in mid-July, the northern regions also experienced severe flooding. Overall, the average rainfall during this period surged to 56% above normal levels, exacerbating the flood situation across Kerala. The impact of the floods and landslides in 1961 was devastating, with 115 lives lost and over 50,000 houses suffered partial or complete damages. Additionally, approximately 115,000 acres of paddy fields were severely affected, highlighting the widespread destruction caused by the disaster.

Rajeevan et al. (2012)[3] analyzed historical rainfall data and hydrological modeling to study extreme rainfall events leading to floods in Kerala. Their study highlighted the influence of synoptic weather systems such as depressions and low-pressure systems in causing intense rainfall during the monsoon season. Research conducted by Singh and Kumar (2013)[4] shed light on the occurrence and impact of flood events across India from 1978 to 2006. Their study revealed significant insights into Kerala's vulnerability to flooding during this period. Specifically, Kerala ranked as the 4th most affected state in terms of the frequency of flood events, 15th in terms of fatalities, and the 14th in case of casualties among all Indian states.

One of the primary drivers behind the floods in Kerala during 1995 and 2005 was the relentless onslaught of heavy rains. These rainfall patterns exacerbated the region's susceptibility to inundation, leading to considerable damages and loss of life. Singh and Kumar (2013) findings underscore the scale of the challenge posed by flooding in Kerala. They reported a total of 1,437 flood events during the examined period, accounting for 3.2% of all flood events in India. Additionally, the flood death rate per million in Kerala was recorded at 36.6, highlighting the significant human toll exacted by these calamities5.

In August 2018, state of Kerala was ravaged by severe floods, precipitated by an unprecedented deluge during the monsoon season. Regarded as the most devastating flood in Kerala in the past century, the calamity resulted from exceptionally high rainfall. Official records and various sources indicate that the death toll surpassed 483 individuals, with 14 individuals still unaccounted[5]. Nearly one million people were evacuated from affected areas during the crisis, prompting a state of emergency across all 14 districts. The Kerala government reported that approximately one-sixth of the state's population bore direct consequences from the floods and associated incidents. Recognizing the severity of the situation, the Government of India classified the disaster as a ***L3 Calamity***[6] *(corresponds to a nearly catastrophic situation or a very large-scale disaster that overwhelms the State and District authorities, signifying its grave nature). This catastrophe stands as the worst flood to afflict Kerala since the catastrophic inundation of 1924, known as the "Great Deluge of '99".*

In 2020, four districts in Kerala were flooded on 7 August 2020 (Idukki, Wayanad, Malappuram and Kottayam). Major reported incidents in relation to flooding include a landslide in Idukki district

[3] Rajeevan, M., Unnikrishnan, C. K., Bhate, J., Niranjan Kumar, K., & Sreekala, P. P. (2012). Northeast monsoon over India: variability and prediction. *Meteorological Applications*, *19*(2), 226-236.
[4] Singh, O., & Kumar, M. (2013). Flood events, fatalities and damages in India from 1978 to 2006. Natural hazards, 69, 1815-1834.
[5] Sharma, A., & Sharma, B. Flood disasters in India: lessons from kerala floods. Culture of Learning and Experimentation, 191.
[6] High Power Committee Report on Disaster Management (2001)

on 6 August, claiming 66 lives and an Air India plane crash that caused the death of 21 people[7]. The 2020 flood in Kerala marked the third year in a row of severe monsoon flooding.

In October 2021, Kerala experienced a severe rainfall event that led to devastating floods and landslides, particularly impacting the districts of Kottayam and Idukki. As the rain intensified on October 15 and continued through the weekend, these areas were battered by exceptionally high rainfall 305.5 mm in Idukki and 164.5 mm in Kottayam triggering widespread landslides and river flooding. This natural disaster caused significant infrastructure damage, with roads being washed away, homes destroyed, and trees uprooted. Many villages, especially in hilly regions, were completely cut off, and at least 26 lives were tragically lost due to landslides and flooding[8].

The deadly floods and resulting landslide of July 30, 2024 (known as Wayanad Landslide 2024, detailed under Landslide section) is a reminder of the increasing vulnerability of the State.

In summary, floods are a recurring natural hazard in Kerala, often exacerbated by heavy monsoon rains both in frequency and intensity due to the impact of climate change and topographical factors. Historical events such as the floods of 1924, 1961, 2018, 2019, 2020, 2021 and 2024 have had significant socio-economic impacts in the State. These disasters have prompted extensive scientific research in the State to understand increasing flood dynamics and Govt. of Kerala is fully geared-up for mitigating their impacts.

Review of Flood Atlas of India by NRSC[9]:

"Flood Atlas of India" was prepared by National Remote Sensing Centre (NRSC) and published by NDMA (2023) reported that major flood events in Kerala (Table 2-1) and district wise flood affected area in Kerala for the period of 1998-2022 as shown in Table 2-2.

Table 2-1: Major flood events in Kerala (Source: NRSC)

S. No.	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 5th -12th, Aug 2005 due to heavy rains.	3
2	2010	Floods were reported in many parts of Kerala due to heavy rains during 4th week of Nov 2010.	2
3	2011	Heavy rains lashed many parts of Kerala during the 1st week of June 2011.	1
4	2012	Floods were reported in Kerala during 1st week of Aug 2012 due to torrential rains.	4
5	2018	Floods occurred during 16th-21st July, 9th - 27th Aug due to heavy rains	8
6	2019	Floods were reported in Kerala due to heavy torrential rains during second week of August, 2019. 10th -14th Aug 2018	7
7	2020	Floods were reported in Kerala during second week of Aug, 2020. 8th - 12th Aug 2020 due to heavy rains	5
8	2022	Floods occurred due to heavy rains were reported in Kerala state during the last week of July 2022	7

[7] Achu, A. L., Joseph, S., Aju, C. D., & Mathai, J. (2021). Preliminary analysis of a catastrophic landslide event on 6 August 2020 at Pettimudi, Kerala State, India. Landslides, 18, 1459-1463.

[8] https://reliefweb.int/report/india/situation-report-kerala-floods-and-landslides-date-18-10-2021

[9] https://ndma.gov.in/sites/default/files/PDF/FHA/Flood_Affected_Area_Atlas_of_India.pdf

Table 2-2: District wise statistics of Flood affected areas in Kerala (Source: NRSC)

S. No.	District	Flood Affected Area (ha)
1	Kottayam	21,379
2	Thrissur	19,562
3	Alappuzha	12,187
4	Ernakulam	7,663
5	Pathanamthitta	6,052
6	Malappuram	5,989
7	Palakkad	4,137
8	Kollam	1,829
9	Wayanad	469
10	Kozhikode	110
TOTAL		79,377

2.1.1.2 Landslides:

Landslides in Kerala, particularly in the Western Ghats region, have been a recurring hazard with significant socio-economic and environmental implications.

In Kerala State, with the exception of the coastal district of Alappuzha, all 13 out of the 14 districts are susceptible to landslides. Approximately 8% (1,400 sq. km) of the area in the Western Ghats region of Kerala is categorized as a ***critical zone for mass movements*** *(Thampi et al., 1995)[10]. This region experiences various types of landslides, particularly during the monsoon season, including rock falls, rock slips, slumps, creeps, debris flows, and rotational slides in some instances. Among these, the most common and devastating type of mass movement observed in Kerala is the "debris flow," locally known as "****Urul Pottal****". This phenomenon is characterized by the rapid and sudden downhill movement of highly water-saturated material, ranging from soil particles to large boulders, which destroys and carries away everything in its path[11].*

Several studies have focused on landslide hazard assessment and mapping in Kerala, utilizing a variety of methodologies and approaches. Thampi et al. (1995) conducted a pioneering study on landslide hazard zonation mapping in Kerala, identifying critical zones for mass movements using geospatial techniques. In 1998, Thampi et al. (1998) conducted a detailed analysis of various landslide types observed in Kerala, including rock falls, rock slips, slumps, creeps, and debris flows. The study emphasized the prevalence of debris flows, as the most destructive type of landslide in Kerala due to their rapid and unpredictable nature. Understanding the characteristics and behavior of different landslide types (Figure 2-2) is crucial for assessing their potential impacts and suggesting effective mitigation measures.

Building upon this work with subsequent studies by Kumar et al. (2016) and Narendran et al. (2019), the RMSI team employed remote sensing and GIS techniques to map landslide susceptibility and monitor changes in landslide-prone areas over time. These studies have

[10] Thampi, P. K., Mathai, J. O. H. N., & Sankar, G. (1995, August). A regional evaluation of landslide prone areas in the Western Ghats of Kerala. In national seminar on landslides in Western Ghats (pp. 29-30).

[11] Thampi, P. K., Mathai, J., Sankar, G., & Sidharthan, S. (1998). Evaluation study in terms of landslide mitigation in parts of Western Ghats. Kerala, Centre for Earth Science Studies, Government of Kerala, Thiruvananthapuram, India, 100.

contributed valuable insights into the spatial distribution of landslide hazards.

The triggering factors of landslides in Kerala are multifaceted and include both natural and anthropogenic factors. Heavy rainfall is a primary trigger for landslides in the region (Kumar et al., 2016). Geological factors such as slope steepness, soil composition, and geological structure also play a significant role in landslide susceptibility (Narendran et al., 2019). Additionally, land cover changes, deforestation, road construction, and other human activities have been identified as contributing factors to landslide occurrence (Gowtham et al., 2020). Understanding the complex interactions between these factors is essential for effective landslide risk assessment and mitigation planning.

Assessing the socio-economic and environmental impacts of landslides is crucial for identifying vulnerable areas and populations and prioritizing mitigation measures. Kumar et al. (2020) conducted a vulnerability assessment of landslide-prone areas in Kerala, considering factors such as population density, infrastructure, and land use patterns. The study highlighted the disproportionate impacts of landslides on marginalized communities and emphasized the need for targeted interventions to enhance resilience and reduce vulnerability.

In addition to 2018 landslides, the 2019 landslides, such as the Kavalappara landslide of 2019, have resulted in significant loss of life and property (Srinivas et al., 2020). The July 30, 2024 flood and landslide resulting in Wayanad, Kerala, 2024 is among the deadliest landslides the state has seen in recent decades. This landslide, triggered by unusually heavy monsoon rains claimed hundreds of lives and swept away hundreds of buildings, leaving vast areas uninhabitable. A review of satellite imagery of the region revealed extensive damage that stretched downhill and into river basins. Mundakkai and Chooralmala are the two of the worst-affected villages, which experienced extensive damage and destruction of life and property.

Review of Landslide Atlas of India by NRSC[12]:

Landslide atlas prepared by NRSC and published by NDMA ranked various districts of India for their exposure to landslides. Table 2-3 displays the ranks of Kerala districts for their incidence to landslide exposure.

Table 2-3: Table shows the rank of districts of Kerala for their exposure to landslides.

District Rank	District	State
3	Thrissur	Kerala
5	Palakkad	Kerala
7	Malappuram	Kerala
10	Kozhikode	Kerala
13	Wayanad	Kerala
15	Ernakulam	Kerala
18	Idukki	Kerala
24	Kottayam	Kerala
26	Kannur	Kerala
28	Thiruvananthapuram	Kerala
33	Pathanamthitta	Kerala
44	Kasaragod	Kerala
48	Kollam	Kerala
138	Alappuzha	Kerala

12 https://ndma.gov.in/sites/default/files/PDF/Landslide_Atlas_2023.pdf

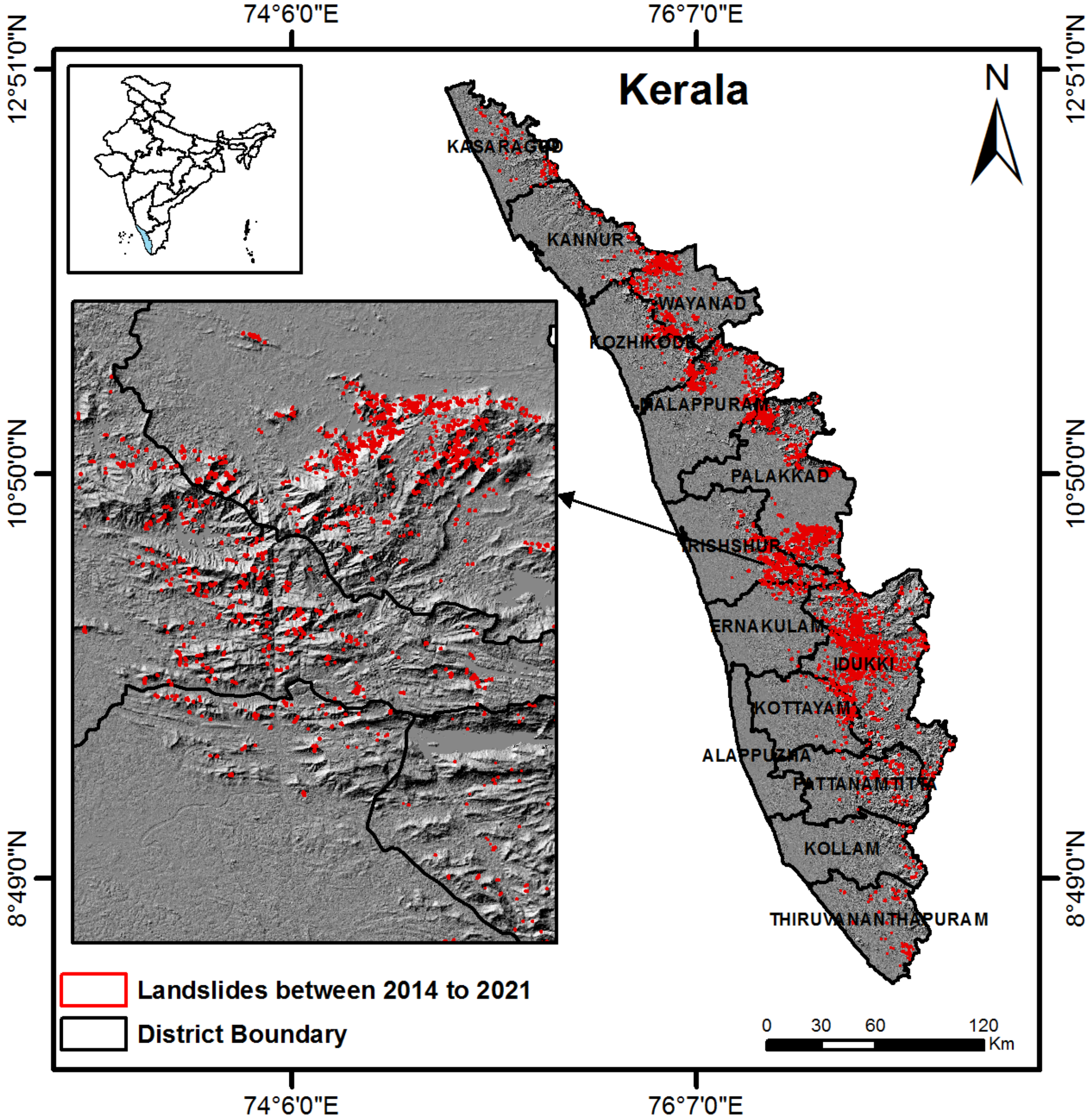

Figure 2-1: Landslides mapped using high-resolution satellite data in Kerala which, occurred between 2014 to 2021 (Source: NRSC).

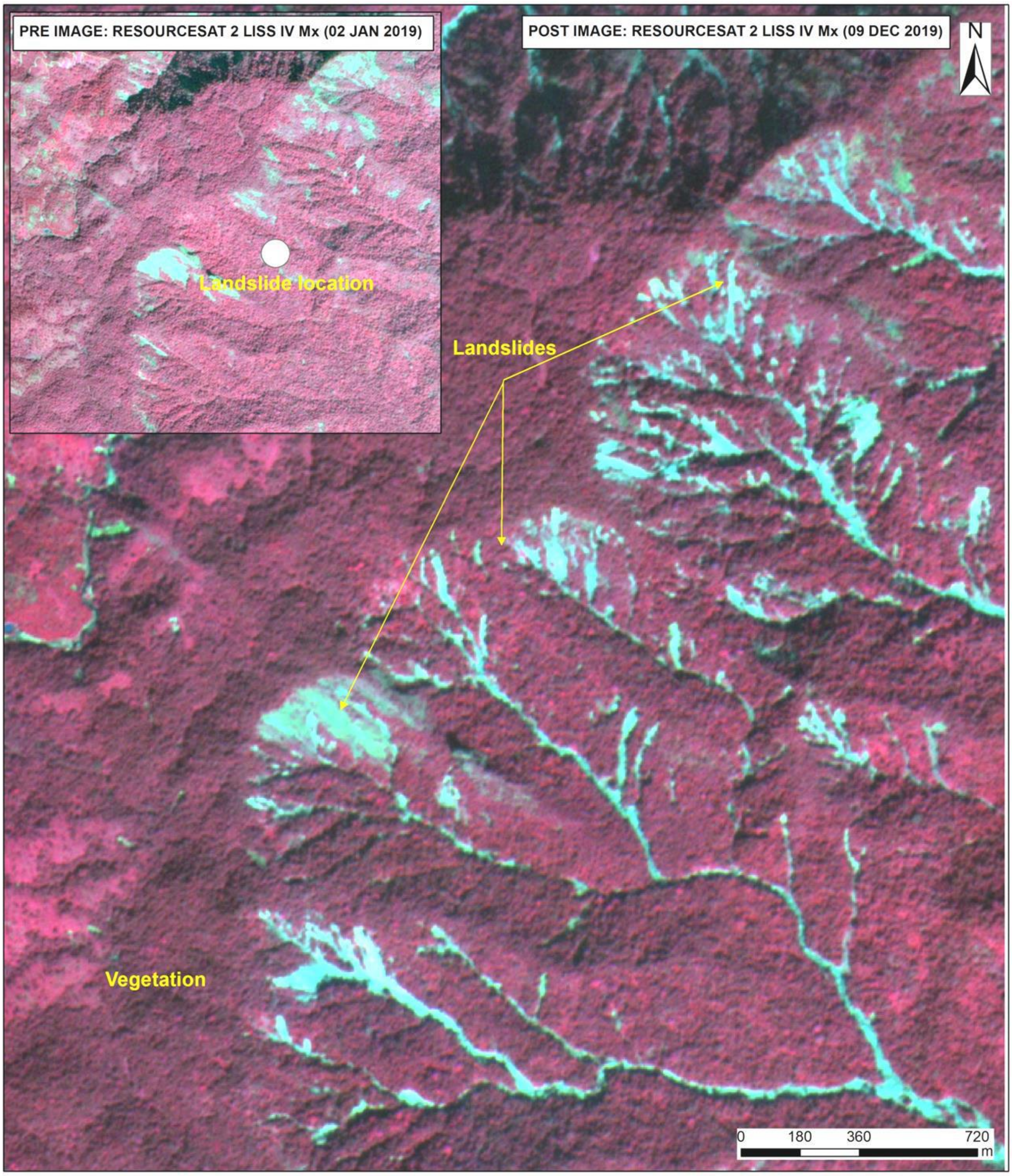

Figure 2-2: Landslide from Puthumala region, Wayanad district, Kerala. Most of these landslides are channelized debris flow

2.1.1.3 Flood and Landslide

Detailed literature review of flood and landslides in Kerala have provided in Table 2-4. More details on major landslides and flood events in the State has given as below:

2.1.1.3.1 Extreme Rainfall and associated floods and landslides (2012) [13]

In 2012, floods and landslides were reported from six districts namely Kannur, Kozhikode, Palakkad, Ernakulam, Idukki, and Kottayam. Flood situation prevailed in Iritty town in Kannur district as the region has experienced very heavy rainfall. As a consequence, Pazahsshi Dam in Iritty town overflowed and aggravated the disastrous situation. The photographs depicting damages due to landslides and floods in Kerala, 2012 are depicted in Annexure 9.1.

- ***Kannur**: Two landslides were reported from Karikottakiri and Murikkan Kara in Ayyankunnu Village, Thalasherry Taluka on 6th and 7th August. On these days, the region experienced a >100-year return interval rainfall which resulted in the flooding of Iritty township and the overflowing of Pazhassi dam. One fatality was reported. On 26th August a landslide was reported from Thirumeni village and Thalasherry Taluka which damaged the arterial road of the village.*
- ***Kozhikode**: Over 35 minor and major debris flows were reported from Pullorampara Anakkampoyil region on 6th August 2012. Acres of crop land perished and 8 fatalities were reported.*
- ***Palakkad**: A debris flow occurred at 100 acres, Ambalappara, Kottappadam Panchayath with in the Silent Valley National Park Buffer Zone. The event was reported on 22nd August as the region is only accessible by foot and is an abode of forest dwelling tribal communities. The actual date of occurrence is unknown. The hill which was affected is the origin of Vaniyampara river and it houses numerous medicinal plants thus resulting in loss of biodiversity.*
- ***Ernakulam:** A major debris flow occurred in Kadavoor village of Kothamangalam Taluka on 17th August 2012. Six fatalities were reported, in addition to significant loss to property.*
- *Estimated loss as per CRF Norms: Rs. 2,656.54 lakhs (Rs. 26.57 crores)*

2.1.1.3.2 Kerala Floods & Landslides (2018)[14][15]

<u>Monsoon related disasters - 29th May to 31st July 2018:</u>

In total 363 villages have been affected due to monsoon related disasters. Forty-seven (47) landslides occurred in the state. According to National Remote Sensing Agency of ISRO, 55,007 ha of land in Kerala was inundated on 16-7-2018. Such catastrophe due to monsoon rainfall has been witnessed for the first time since 1924, in the state. Table 2-5 shows district wise damage and economic loss statistics due to floods and landslides in Kerala during the period of 29th May to 31st July 2018.

<u>Monsoon related disasters 1st August to 31st August 2018:</u>

The heavy monsoon of 2018 in particular brought widespread flooding to several districts of Kerala state and triggered a large number of small to big landslides. The extreme and prolonged rainfall spell in August 2018 led to the worst flooding in Kerala in nearly a century impacting almost 5.4 million people - one-sixth of the State's population. Several districts were inundated for more than two weeks due to

[13] https://sdma.kerala.gov.in/wp-content/uploads/2018/11/9.Memorandum-Landslides-2012.pdf

[14] https://sdma.kerala.gov.in/wp-content/uploads/2019/08/Memorandum1-Floods-2018.pdf

[15] https://sdma.kerala.gov.in/wp-content/uploads/2019/08/Memorandum2-Floods-2018.pdf

heavy rains induced floods. The torrential rains triggered several landslides and forced the release of excess water from 37 dams across the State, adding to the impact of floods. Nearly 341 major landslides were reported from 10 districts. Idukki district was ravaged by 143 landslides. 1,260 out of 1,664 villages spread across its 14 districts were affected. Seven districts were worst hit: Alappuzha, Ernakulam, Idukki, Kottayam, Pathanamthitta, Thrissur, and Wayanad where the whole districts were notified as flood affected. Figure 2-5 represents spatial distribution of landslide/ mudslides that occurred in 2018.Table 2-6 shows district wise damage and economic loss statistics due to floods and landslides in Kerala during the period of 1st August to 31st August 2018.

According to KSDMA memorandum reports, the combined estimated losses from these two events were INR 789 crore for reconstruction and INR 2,658 crore for the economic sector. The Post-Disaster Needs Assessment (PDNA) estimates that the total damages amount to approximately INR 10,557 crore and total losses to be around INR 16,163 crore, resulting in a combined disaster effect of approximately INR 26,720 crore (USD 3.8 billion)[16]. These figures do not include damage estimates from the Joint Rapid Damage and Needs Assessment (JRDNA) conducted by the World Bank and the Asian Development Bank (ADB). The total estimated damages exclude those to private buildings and properties, such as shops, showrooms, business units, private hospitals, educational institutions, and private vehicles.

Additionally, the losses incurred by private traders and business units, as well as the damage and loss suffered by Kochi airport, road transport, and waterways, are not accounted for in this estimate. If these were included, the total damage and loss, currently estimated at INR 26,720 crore, would be significantly higher.

2.1.1.3.3 Kerala Floods & Landslides - 2019[17]

Year 2019 marked as yet another year when Kerala received significantly heavy rainfall all across the state. It resulted in a large number of landslide and mudslide incidences of varying intensities. Table 2-7 shows district wise damage and economic loss statistics due to floods and landslides in Kerala, 2019.

2.1.1.3.4 Extreme rain induced hazards in Kerala (2021)[18]

In October 2021, once again the state of Kerala was hit by torrential rain causing flooding and triggering a series of landslides. Extreme rainfall events in Kerala from 11th to 26th October 2021 resulted state to receive widespread heavy rainfall. The cyclonic circulation in the North Andaman Sea and the neighborhood strengthened the monsoon westerlies and has caused widespread very heavy rainfall over the Kerala state. Figure 9-5 to Figure 9-8 show photos taken from some of the locations affected by landslides in 2021.

Table 2-4: Literature review for flood and landslide

S. No.	Peril	Title	Details
1.	Landslide	History of landslide susceptibility and a chorology of landslide-prone	• This study surveyed 29 major landslide events in Kerala that occurred from 1984 to 2008 and

[16] https://www.undp.org/publications/post-disaster-needs-assessment-kerala#:~:text=December%2012%2C%202018&text=Nearly%20341%20landslides%20were%20reported,state's%2014%20districts%20were%20affected.

[17] https://sdma.kerala.gov.in/wp-content/uploads/2020/03/Memorandum-pages-deleted-Copy-compressed.pdf

[18] https://sdma.kerala.gov.in/wp-content/uploads/2022/05/Event-report_October-2021.pdf

S. No.	Peril	Title	Details
		areas in the Western Ghats of Kerala, India Author: Sekhar L. Kuriakose, G. Sankar, C. Muraleedharan Year: 2009 Year of Occurrence: 1984 to 2008	suggested that the initiation zones of most of the landslides were typical hollows, generally having degraded natural vegetation. • Except coastal district of Alappuzha, majority of districts in Kerala are prone to landslides. • Wayanad and Kozhikode districts are prone to deep seated landslides, while Idukki and Kottayam districts are prone to shallow landslides.
2.	Flood and Landslide	Landslides and Flood Losses – 2012 Author: Department of Disaster Management, Government of Kerala Year: 2012 Year of Occurrence: 2012	• Landslides were reported from six districts namely Kannur, Kozhikode, Palakkad, Ernakulam, Idukki, and Kottayam. • Due to heavy rainfall, Pazhassi Dam in Iritty town overflew aggravating the disastrous situation and led to 16 causalities. • Landslides caused severe damages to 541 hectares of perennial crops
3.	Flood, Landslide and Wind	Monsoon Calamity Losses – 2013 Author: Department of Disaster Management, Government of Kerala Year: 2013 Year of Occurrence: 2013	• Landslides were reported from Kozhikode, Palakkad, Idukki, and Pathanamthitta districts of Kerala due the unexpected exceed of South West Monsoon between 1st- 30th June, 2013 • Floods, windfall and landslides have caused severe damages to the crops.
4.	Landslide	Monsoon Calamity Losses - 2014 Author: Department of Disaster Management, Government of Kerala Year: 2014 Year of Occurrence: 2014	• Intense pre-monsoon rainfall in the month of April, 2014, especially along the southern districts of Kerala (Thiruvananthapuram to Ernakulam) led to some isolated cases of landslides.
5.	Flood and Landslide	Kerala Floods – 2018 Author: Department of Disaster Management, Government of Kerala Year: 2018 Year of Occurrence: 2018	• 96% excess rainfall than the average long period rainfall from South west monsoon caused significant damages to life and property. • Kerala State Disaster Management Plan (SDMP) identified 14.4% of the State as landslide prone. Land Revenue Department reported 331 landslides, rock slides, and landslips in all districts in Kerala, of which Idukki district was the most badly affected.
6.	Flood and Landslide	Kerala Floods – 2019 Author: Department of Disaster Management, Government of Kerala	• Between August 8 and 31, 2019, Kerala experienced flood and landslides due to the influence of low-pressure area and depression formed over the Bay of Bengal and

S. No.	Peril	Title	Details
		Year: 2019 Year of Occurrence: 2019	strengthening of Monsoon winds, Kerala. • Kerala received 123% excess rainfall than the average long period rainfall in August. • 13 out of 14 districts in Kerala were notified as affected by floods & landslides and have caused exorbitant damages to the agriculture sector.
7.	Landslide	Land Degradation in the Western Ghats: The Case of the Kavalappara Landslide in Kerala, India Author: Nirmala Vasudevan, et. al. Year: 2022 Year of Occurrence: 2019	• Kavalappara landslide that occurred in 2019 resulted in the loss of 59 lives and considerable damages to property. • This study suggested that the human activities aggravated the slope instability such as, conversion of natural vegetation to plantations, step cutting of slopes, construction of soak pits, construction of homes on natural drainage channels, and improper methods of drainage.
8..	Landslide	Preliminary analysis of a catastrophic landslide event on 6 August 2020 at Pettimudi, Kerala State, India Author: Achu, A.L., et al. Year: 2021 Year of Occurrence: 2020	• Pettimudi landslide was one of the disastrous landslides that occurred in the Pettimudi village of Idukki district, Kerala and this study suggested that it was initiated on the steep slopes of Shola Forest and its lid through the tea plantations and approx. 70,125 m^2 area was estimated to be affected by the landslide.
9.	Landslide	The tale of three landslides in the Western Ghats, India: lessons to be learnt. Author: R. S. Ajin, et. al. Year: 2022 Year of Occurrence: 2021	• This study observed three landslides that occurred on 16th October 2021: Kokkayar landslide, Plappally landslide, and Kavali landslide. • Study suggested that Kokkayar landslide was completely caused by humans; Plappally landslide was affected by geomorphic and tectonic causes, and Kavali landslide was caused by forest fragmentation.
10.	Landslide	Impact of anthropogenic activities on landslide occurrences in southwest India: An investigation using spatial models Author: Jones, S., Kasthurba, A.K., et. al. Year: 2021	• This study suggests that the Landslide hotspots are concentrated in Idukki, Ernakulam, Kottayam, Wayanad, Kozhikode and Malappuram districts of Kerala. • Nearly 59.38% of total landslides in Kerala have occurred in the plantation areas and about 64.76% of the state's total landslides have

S. No.	Peril	Title	Details
			happened in the human-modified land-uses.
11.	Landslide	Evaluating the relation between land use changes and the 2018 landslide disaster in Kerala, India Author: Lina Hao, et. al. Year: 2022	• LULC classes from 8 years (from 2010 to 2018) were correlated at the landslide initiation points. Highest landslide density found in the built-up areas within Idukki district and were related to cut slope failures.

Table 2-5: Monsson calamity losses due to 29th May to 31st July 2018 floods and landslides (Modified after KSDMA 2018 memorandum1)

District	Total Deaths	No. People Affected	No. Houses damaged	PWD Roads (Km)	Bridges	Schools	Primary Health Centres	Agriculture land affected (ha)	Total Economic loss (INR Crore)
Thiruvananthapuram	7	626	1,319	202.00	-	44	14	325.59	48.24
Kollam	3	606	788	354.57	-	3	2	354.87	39.66
Pathanamthitta	8	14,607	1,544	844.65	23	19	7	91.53	53.72
Kottayam	9	61,155	781	-	12	85	29	5,103.46	78.44
Alappuzha	12	4,98,518	619	380.63	27	148	57	13,087.75	97.86
Idukki	5	278	855	933.57	-	16	8	2,608.17	42.36
Ernakulam	6	7,557	531	527.56	-	26	9	589.72	81.98
Thrissur	11	10,935	338	557.87	2	16	7	812.82	50.05
Palakkad	4	250	527	1,163.42	1	194	63	2,140.57	60.38
Malappuram	13	286	602	1,991.00	3	-	-	1,020.50	43.86
Kozhikode	21	6,083	2,518	760.00	-	4	-	278.17	69.39
Wayanad	5	5,780	430	436.44	-	-	6	541.04	12.53
Kannur	22	106	965	581.95	-	-	1	294.87	58.32
Kasaragod	12	80	285	46.70	-	1	-	110.08	17.32

Source: KSDMA memorandums

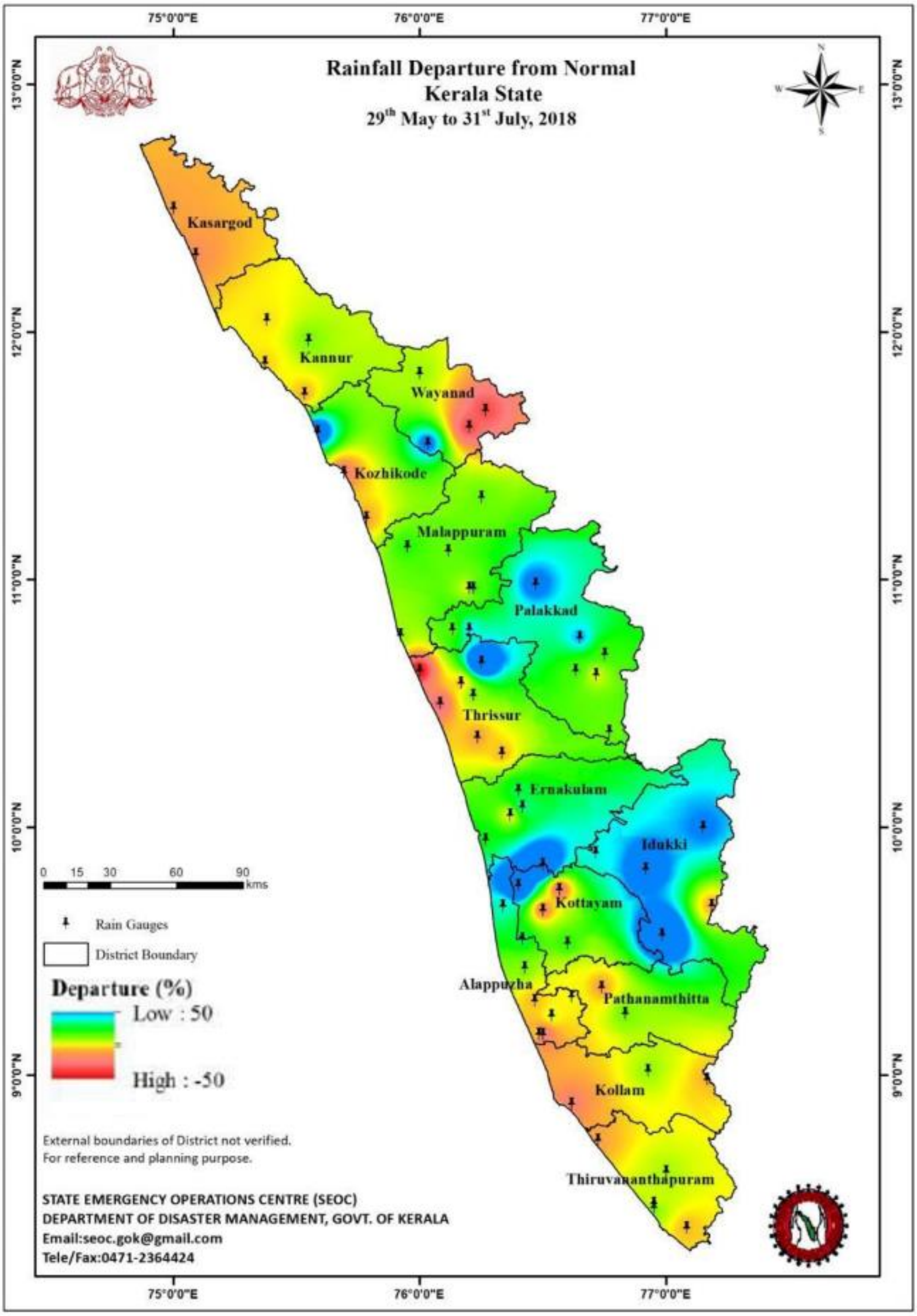

Figure 2-3: Rainfall departure 2018 (29th May to 31st July) (Source: IMD)

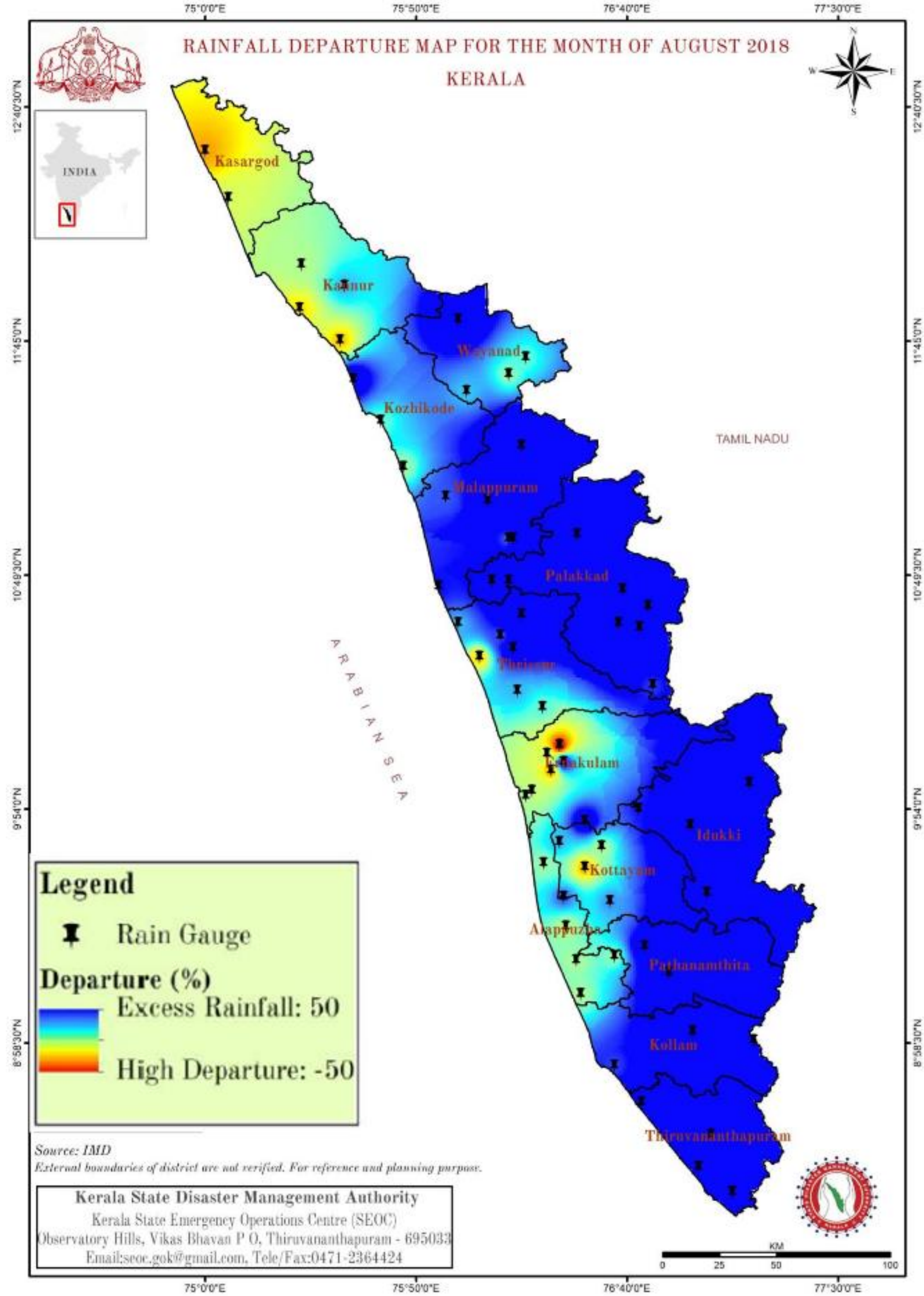

Figure 2-4: Rainfall departure for the month of June 2018 (Source: IMD)

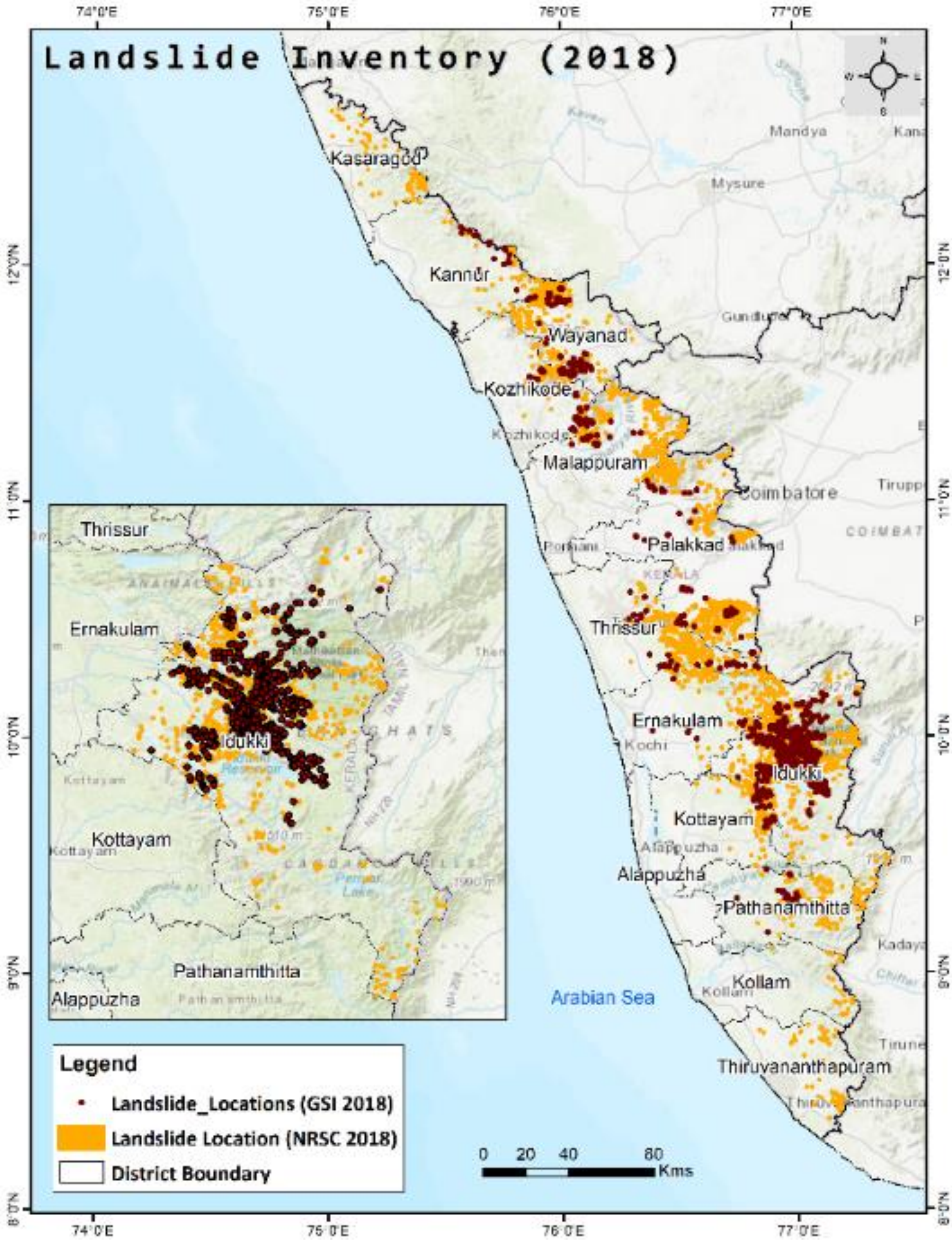

Figure 2-5: Spatial distribution of landslide locations in Kerala, 2018

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Table 2-6: Monsson calamity losses due to 1st to 31st August 2018 floods and landslides (Modified after KSDMA 2018 additional memorandum)

District	Total Deaths	No People Affected	No Houses damaged	PWD Roads (km)	Bridges	Schools	Primary Health Centers	Agriculture land affected (ha)	Total Economic loss (INR Crore)
Thiruvananthapuram	11	8,662	3,051	475.00	5	6	2	1,356.96	51.06
Kollam	5	21,550	1,433	340.00	48	28	8	869.73	37.73
Pathanamthitta	3	8,07,911	33,516	550.00	68	46	4	12,085.05	474.89
Alappuzha	43	7,36,316	21,065	241.00	56	90	42	12,095.55	46.45
Kottayam	14	2,49,085	732	291.00	6	33	4	7,170.71	271.70
Idukki	54	2,498	2,299	2,105.00	121	37	20	5,745.97	102.43
Ernakulam	58	8,46,419	2,611	2,130.00	13	56	22	1,296.66	155.22
Thrissur	72	5,14,366	21,130	598.00	41	15	15	3,569.25	341.38
Palakkad	20	16,684	4,722	164.00	78	26	22	6,250.43	132.75
Malappuram	30	42,099	4,231	1,231.00	18	24	27	5,275.40	113.16
Kozhikode	16	53,636	1,445	332.00	8	7	7	627.04	49.35
Wayanad	6	60,847	9,952	565.00	9	35	6	1,876.80	52.59
Kannur	6	2,498	3,337	100.00	20	9	6	926.53	62.70
Kasaragod	1	375	77	416.45	19	4	3	199.29	12.12

Source: KSDMA memorandums

Table 2-7: Losses due to 2019 flood and landslide (Modified after KSDMA 2019 memorandum)

District	Total Deaths	No Houses damaged	PWD Roads (Km)	Bridges	Schools	Primary Health Centres	Agriculture land affected (ha)	**Total Economic loss (INR Crore)**
Thiruvananthapuram	-	205	-	-	-	-	-	8.02
Kollam	-	484	108.88	-	-	1	278.76	6.83
Pathanamthitta	-	3,929	110.32	-	-	-	335.89	20.77
Alappuzha	6	15,758	56.75	7	3	-	3,644.13	68.32
Kottayam	2	26,496	323.02	2	4	1	2,862.05	50.31
Idukki	5	245	489.74	2	4	2	999.28	24.00
Ernakulam	-	14,064	320.53	11	-	2	1,294.21	55.19
Thrissur	9	23,144	458.96	13	7	6	2,653.42	202.87
Palakkad	1	7,179	379.48	21	10	7	10,885.86	56.89
Malappuram	60	48,012	414.76	14	10	10	1,611.30	174.24
Kozhikode	17	47,534	202.50	9	6	6	274.80	144.79
Wayanad	14	9,079	401.28	3	13	4	3,661.18	74.04
Kannur	9	15,185	132.03	11	12	6	14,963.00	79.69
Kasaragod	2	5,146	226.21	-	6	4	388.26	15.90

Source: KSDMA memorandums

2.1.1.4 Wayanad flood and landslide July 30, 2024

One notable historical instance occurred in August 2019, when Wayanad experienced severe landslides following incessant rainfall. The landslides were part of a broader disaster across Kerala that year, resulting in loss of life, displacement of people, and extensive damage to property. The 2018 Kerala floods, which were among the worst in nearly a century, also triggered several landslides in Wayanad, further highlighting the vulnerability of the region. So, it is well known, that Wayanad area is an area having high susceptibility to landslides.

Wayanad, a hilly district in the Western Ghats Mountain range, is prone to landslides during heavy and consistent rains particularly during the monsoon season. Due to heavy rainfall in the area on July 30, 2024 a major landslide event occurred which cause widespread damage to property and also resulted in loss of several hundred precious lives. An estimated 570 mm of rainfall was recorded in the two days preceding the disaster.

Figure 2-6: Some of the images from Wayanad post landslide event on July30, 2024

A landslide happened on July 30, 2024, at 02:17 hours, near Mundakki, Chooralmala, Vellarimala Village in Meppadi Panchayat, Vythiri Taluk, Wayanad District, as a result of continuous heavy to extremely severe rains. The landslide diverted the Iruvazhinji River, resulting in flash floods and washing away the Chooralmala village. Approximately families were stranded in Mundakkai and Attamala following the collapse of the only bridge connecting the settlements and Chooramala. Overall, six villages, namely Punjirimattom, Meppadi, Mundakkai, Attamala, Chooralmala, and Kunhome, were affected by the landslides. Some of the damage photographs have depict in Figure 2-6.

Wayanad landslide on 30th July has been the worst landslide event in the known history of Kerala state resulting into death of 298 people (personal communication), leaving hundreds injured and hundreds of others missing.

RMSI has conducted a detailed study on landslide susceptibility mapping at high resolution (100m x 100m) using machine language (ML) modelling approach. Study indicates that the major parts of the impacted villages in Wayanad were mapped as high to very high landslide prone areas (Figure 2-7). The landslide occurred on one of the old landslide sites at least 6 km uphill away from the most impacted villages.

Although excessive rains and climate changes has been pointed out as sole cause of this devastation; however, land use change in last couple of decades is not being blamed. In fact, land use in the landslide affected areas takes fair contribution of the disastrous impact. Construction of lot of residential and commercial properties within the river plain and immediate vicinity was probably the reason of blocking/ hindering the active channel to flow/ accommodate such an extensive amount of water resulting into flash flood on either side of the channel. This flash flood water was also laden with debris from the landslide increasing the impact of the flood and washing away almost everything which came in its way.

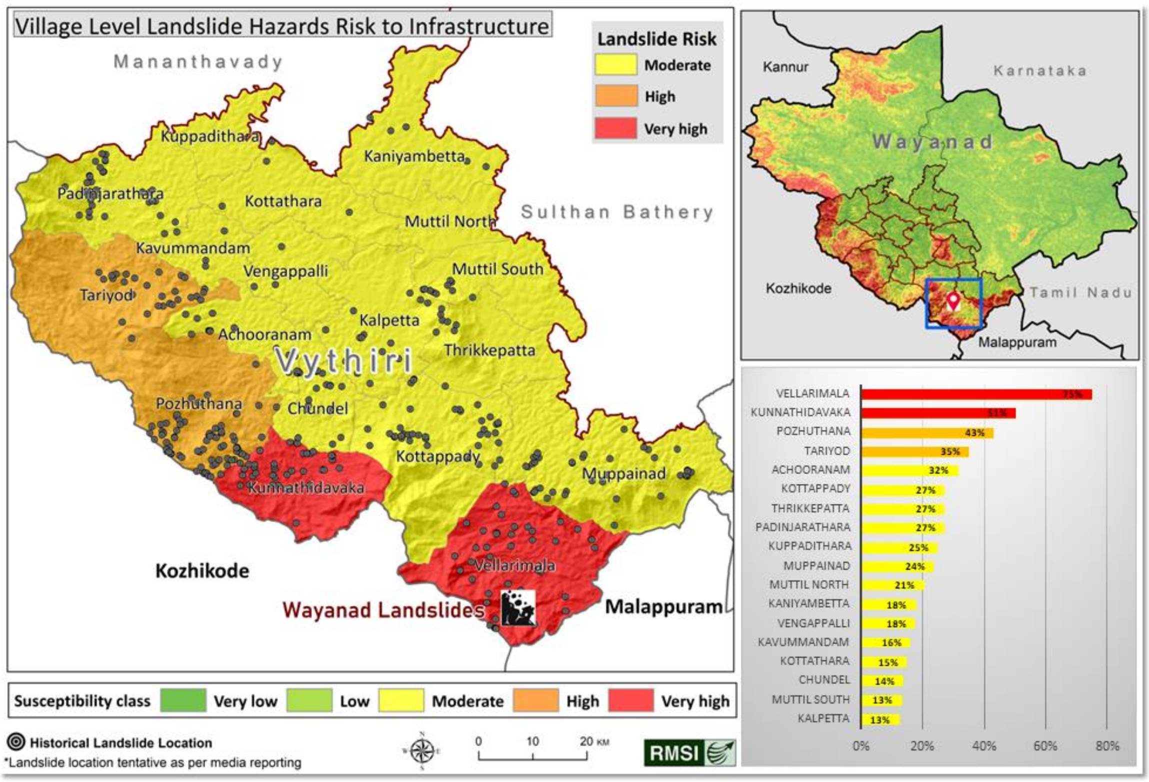

Figure 2-7: Landslide susceptibility map of Wayanad

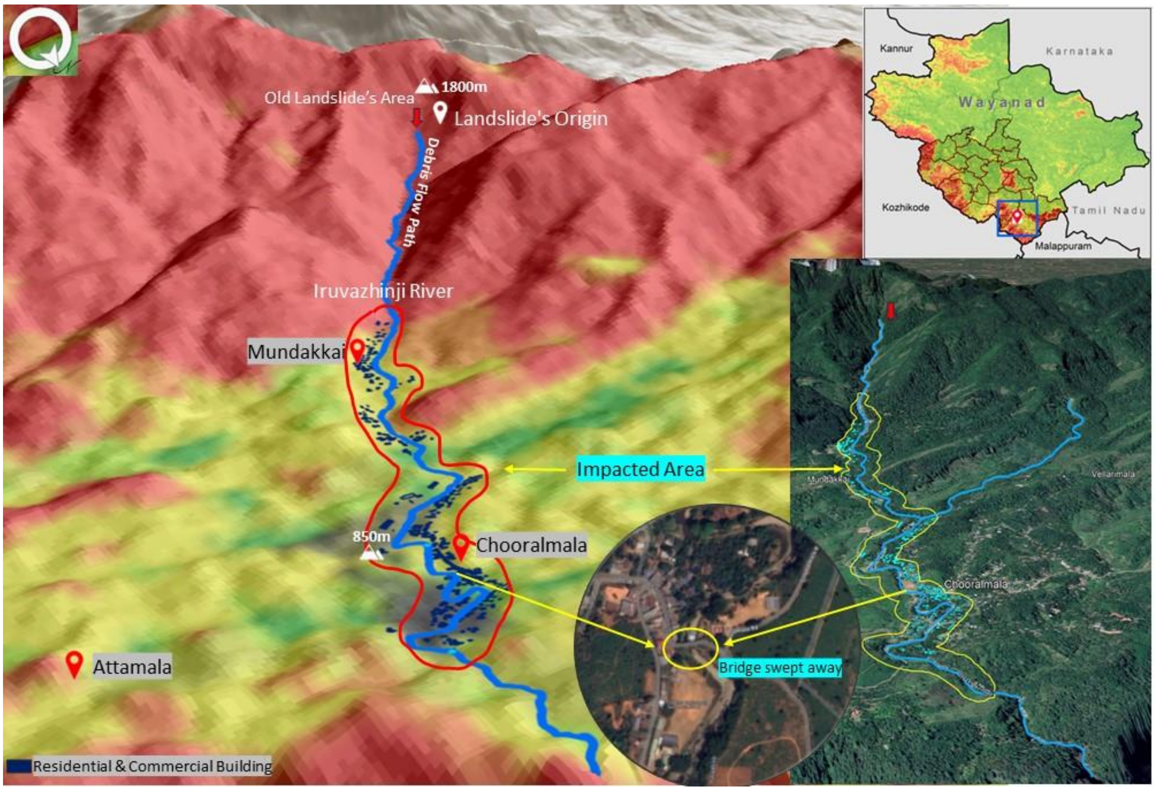

Figure 2-8: showing origin point of landslide and buildings impacted along the stream channel.

Table 2-8: Distribution of historical landslide with respect to distance from streams and rivers

S. No	No of landslides in (0-200 m)	No of landslides in (200-400 m)	No of landslides in (400-600 m)	No of landslides in (>600 m)
1	2874	1976	1642	1112

Review of historical landslides in Kerala particularly the once occurred in recent years show proximity of the events with early order stream channels. Figure 2-8shows spatial distribution of recent landslide events in Kerala and stream channels, whereas Table 2-8 shows distance of these landslides (m) from the nearest stream channels.

Additionally, closer look of the most of the houses and infrastructures hit by landslides in these events indicate that people living in close proximity to these streams/rivers are the ones who were impacted the most.

Similar behavior was also noticed during most of the landslides in 2018 floods and one which occurred in Wayanad on 30th July 2024.

It is important to note that Wayanad landslide/mudslide event is one, in which most of the casualties and devastation occurred at least 6 km away from the landslide origin point. It was mostly the flash flood water loaded with debris from landslide which caused the damage to the structures located in the immediate vicinity of the stream channel. Hence, this event may be referred as Wayanad Flood & Landslide July 30, 2024, instead of 2024 Wayanad Landslide.

2.1.1.5 Tropical Cyclones:

The west coast of India is comparatively less vulnerable to storms than the east coast of India in terms of both the height of storm surge as well as frequency of occurrence. However, so far Kerala state (located on the Arabian Sea coast) has experienced only three Very Severe

*Cyclonic Storm (VSCS) due to its geography and low latitude (shown in Annexure 8). There are several instances when Bay of Bengal cyclones crossed the east coast of India, maintained their intensity over land, and gradually weakened before emerging into the Arabian Sea off Kerala coast. Hence, there are comparatively fewer events that impacted the State from Arabian sea. Table 8-1 of Annexure **1.1** shows the list of historical cyclonic disturbances that affected Kerala along with their damage details.*

Historical cyclonic events, such as Cyclone Ockhi in 2017, have impacted the state (Kumar et al., 2019)[19]. Scientific research has focused on understanding cyclone behavior and enhancing preparedness measures. Mohapatra et al. (2019) analyzed historical cyclone tracks and intensity over the Bay of Bengal and Arabian Sea. Their study highlighted an increasing trend in the frequency of severe cyclones affecting Kerala and emphasized the need for robust disaster preparedness measures. Kumar et al. (2018) conducted a detailed analysis of Cyclone Ockhi, assessing its meteorological characteristics and socio-economic impacts. They underscored the importance of early warning systems and evacuation protocols in reducing cyclone-related casualties. Gupta et al. (2019)[20] studied the Impact of climate change on tropical cyclones frequency and intensity on Indian coasts with the past more than 140 years of and concluded that Cyclone Intensity is increasing both in Bay of Bengal (BoB) and Arabian Sea (AS).

According to the KSDMA report titled "An Integrated Approach to the Preparedness and Mitigation of Cyclone Tauktae: The Case of Kerala[21]", Kerala has been hit mainly by 5 cyclones over the last 127 years. Recently, there were two cyclones, Gaja (16 November, 2018) and Ockhi (28 November- 7 December, 2017), and 2 earlier in 1912 (19-22 November 1912, 17-19 December 1912) and one cyclone in 1925 (06-10 November). The cyclone, which occurred in 1925 (November 06-10), passed through north Kerala on November 10. The cyclone that occurred in November 1912 passed through the southern coasts of Kerala and Tamil Nadu. Ockhi was the fourth cyclone to form in the Comorin Sea (South of Kerala and Tamil Nadu, and west of Sri Lanka). It was after 92 long years that a cyclone passed through the Kerala coast. But Ockhi (2017) did not cross the Kerala-Tamil Nadu coast.

On November 8, 2018, low pressure system formed between Thailand's sea and the Malay Peninsula, entered the Andaman coast in the Bay of Bengal and became the Gaja cyclone. Gaja travelled along the longest track in recent times, crossed the Indian Peninsula for the first time and entered the Arabian Sea at extreme low pressure over Kerala in the afternoon of November 16. Since 1990, this was the first cyclone that formed in the Bay of Bengal and reached the Arabian Sea through Kerala.

2.1.1.5.1 Severe cyclonic storm (SCS) of November 1977

This storm reportedly caused extensive damage in Kerala and Lakshadweep. About 72 people died and 8,400 houses were damaged. Tidal waves were reported to have damaged 620 fishing vessels in coastal areas of Kerala state. Total loss

[19] Kumar, K., E. K., Vijaykumar, P., Sahai, A. K., Chakrapani, B., & Gopinath, G. (2019). Changing characteristics of droughts over Kerala, India: inter-annual variability and trend. *Asia-Pacific Journal of Atmospheric Sciences*, *55*(1), 1-17.

[20] Gupta S., Indu J., Johari P, and Lal, M. (2019). Impact of climate change on tropical cyclones frequency and intensity on Indian coasts, In: Rao, P., Rao, K., Kubo, S. (eds) Proceedings of International Conference on Remote Sensing for Disaster Management. Springer Series in Geomechanics and Geoengineering. Springer, Cham. https://doi.org/10.1007/978-3-319-77276-9_32

[21] https://sdma.kerala.gov.in/wp-content/uploads/2021/10/Cyclone-Tauktae_Case-Study_09-Oct-2021_2300-1.pdf

was estimated to be about 10 crores (SMRC, 1998)[22].

2.1.1.5.2 Severe cyclonic storm (SCS) of November 1992

This cyclone crossed the Kerala and Karnataka coast near Honavar town causing extensive damage to the property in the coastal districts of Tamil Nadu and Kerala. Heavy rains caused flash floods and landslides resulting in considerable damage to the standing crops and houses in Karnataka, Kerala, and Tamil Nadu. According to the press reports about 175 persons lost their lives and 160 people reported missing in Tamil Nadu and Kerala[23,24].

2.1.1.5.3 Cyclone Ockhi - 30 November, 2017

On 30 November, 2017, the Cyclone Ockhi passed by about 70 km away from Kerala coast. Kerala in the last 100 years had not experienced a major Cyclonic Storm impact of this magnitude[25]. As per a report from KSDMA, Kerala state witnessed loss of lives of 51 persons, 234 injured, and 9,134 affected. About 3,744 houses were damaged by cyclone Ockhi in Kerala[26]. A few damage photographs from cyclone Ockhi in Kerala are presented in Figure 9-9 to Figure 9-11 [27].

2.1.1.5.4 Extremely Severe Cyclonic Storm Tauktae 14th -19th May, 2021

Extremely Severe Cyclonic Storm Tauktae (14th -19th May, 2021) generated squally winds[28] of 50-60 kmph with gusts up to 70 kmph along and off the Kerala coast on May 15th. A total of 1,532 houses were damaged in Kerala. Figure 9-12 and Figure 9-13 depict the damage photographs caused by the Extremely Severe Cyclonic Storm Tauktae in Kerala. Besides the above, Kerala witnessed several storms (given in Table 2-9) ranging from tropical depressions (31-61 km/h) to very severe cyclonic storms (88-118 km/h).

Table 2-9: Number of historical cyclone events considered for Kerala (1891-2023)

Category	No. of Cyclonic Disturbances
Depression	3
Deep Depression	3
Cyclonic Storm	8
Severe Cyclonic Storm	3
Very Severe Cyclonic Storm	15
Extremely Severe Cyclonic Storm	4
Super Cyclonic Storm	-

2.1.1.6 Drought

Studying long-term changes and associated extreme hydrological events over a smaller region like Kerala, a Southern Peninsular Indian state, is challenging due to the large heterogeneity in the complex terrain bounded by the Arabian Sea on the west and the Western Ghats on the east. Across the small average width of 100 km in the zonal direction over the complex terrain of Kerala, there exists significant heterogeneity in the land surface and land use characteristics.

Agriculture in Kerala is predominantly rainfed, with less than 30% of the

[22] SMRC (1998). The impact of tropical cyclones on the coastal regions of SAARC countries and their influence in the region, SMRC-No.1, SAARC Meteorological Research Centre, Dhaka, Bangladesh, October 1998, 329 pp.

[23] IMD Report on cyclonic disturbances over North Indian Ocean in 1992- RSMC Tropical Cyclones (1993)

[24] SMRC (1998). The impact of tropical cyclones on the coastal regions of SAARC countries and their influence in the region, SMRC-No.1, SAARC Meteorological Research Centre, Dhaka, Bangladesh, October 1998, 329 pp.

[25] Govt. of Kerala, 2017. Memorandum – Cyclone Ockhi. 30th November 2017 to 17th January 2018. Department of Disaster Management, Govt. of Kerala. Submitted on: 17-01-2018

[26] Memorandum-Ockhi-2017 by Additional Chief Secretary, Disaster Management, Govt. of Kerala (KSDMA).

[27] IMD Report: 2018, Very Severe Cyclonic Storm, 'OCKHI' over the Bay of Bengal (29 Nov - 05 Dec 2017)

28 IMD Report: 2021, Extremely Severe Cyclonic Storm TAUKTAE over the Arabian Sea (14th -19th May, 2021)

agricultural land relying on irrigation. Reports indicate that rainfall over Kerala decreased by 10-20% between 1901 and 1980, particularly during the second half of this period[29]*. In 2016, Kerala experienced one of its most severe droughts, posing a significant threat to both agriculture and hydrology. Additionally, it has been observed that the frequency of drought years has been increasing in Kerala in recent decades. Rajeevan and Pai (2017) analyzed the 2017 drought in Kerala, attributing it to El Niño and the Indian Ocean Dipole. They assessed meteorological factors contributing to the drought and emphasized the importance of drought preparedness measures and water conservation strategies. Studies have also reported weakening trend in land-sea thermal gradient due to rapid ocean warming in contrast to slower land warming and resulting drying of Indian subcontinent*[30]*. The strongest rainfall decreases are observed in July, along the southwest coast of India. In this region (the Western Ghats run parallel to a narrow coast, with an average elevation of 700 m), the reduction of precipitation is likely due to the weakening of vertical velocities caused by upper tropospheric warming*[31]*. The reduction in rainfall over extreme southern peninsular Indian region is caused due to the poleward shift in monsoon Low Level Jet (LLJ) in response to widening of tropical belt under global warming*[32]*. Consistent with this, prominent upper-level circulation feature during monsoon season known as Tropical Easterly Jet (TEJ) is also weakening due to the warming of middle to upper troposphere over equatorial Indian ocean region*[33 & 34]*. Any changes in the pattern of rainfall can have significant impact on the availability of water resources, agriculture and eco system. In 2023, Kerala experienced more deficit in rainfall in June and August months, as compared with the year 2016 as shown in* Table 2-10 (Bulletin: on Manorama).

According to the Indian Meteorological Department (IMD), Kerala experienced 10 moderate drought events and 8 drought-prone years between 1875 and 2004. The state also witnessed drought incidents in three consecutive years: 1951-1952, 1965-1966, and 2002-2003. Kerala has endured 66 drought years between 1881 and 2000, exacerbating water scarcity issues in both urban and rural regions due to dry rivers and declining water tables. The state has also witnessed one of the most distressing droughts in the year 2016, which imposed a severe threat to both agriculture and hydrology. It is also realized that the frequency of drought years is increasing over Kerala during recent decades. Each deficit rainfall year is unique in the sense that its impact on agriculture, hydrology, and the socio-economic sectors varies. Though the southwest monsoon during 2015 was unsatisfactory for Kerala, the annual water stress and severity of drought during 2015 didn't scale up to the level as that of the year 2016[35]*.*

As per SDMA drought situation assessment report for 2017, the Directorate of Agriculture has reported that a total of 41,592 ha has been reported as

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[29] Abhilash, S., Krishnakumar, E. K., Vijaykumar, P., Sahai, A. K., Chakrapani, B., & Gopinath, G. (2019). Changing characteristics of droughts over Kerala, India: inter-annual variability and trend. *Asia-Pacific Journal of Atmospheric Sciences*, *55*(1), 1-17.

[30] Roxy, M., Ritika, K., Terray, P., Murtugudde, R., Ashok, K., Goswami, B.N.: Drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient. Nat. Commun. 6, (2015).

[31] Rajendran, K., Kitoh, A., Srinivasan, J., Mizuta, R., Krishnan, R.: Monsoon circulation interaction with Western Ghats orography under changing climate. Theor. Appl. Climatol. 110(4), 555–571 (2012).

[32] Sandeep, S., Ajayamohan, R.: Poleward shift in Indian summer monsoon low level jetstream under global warming. Clim. Dyn. 45, 337–351 (2014).

[33] Sathyamoorthy, V.: Large scale reduction in the size of the tropical easterly jet. Geophys. Res. Lett. 32(14), (2005).

[34] Abish, B., Joseph, P.V., Johannessen, O.M.: Weakening trend of the tropical easterly jet stream of the boreal summer monsoon season 1950– 2009. J. Clim. 26(23), 9408–9414 (2013).

35 Changing Characteristics of Droughts over Kerala, India: Inter-Annual Variability and Trend Abhilash S.1,2 & E. K. Krishnakumar & P. Vijaykumar & A. K. Sahai & B. Chakrapani & Girish Gopinath.

damaged during 2016-17 Kharif and Rabi period together. Of this, 2286.77 ha were damaged during Kharif and the remaining during Rabi season[36]

According to the Department of Agriculture Development and Farmers' Welfare, Government of Kerala, crop loss FIR summary reports for the period from 01-04-2019 to 23-09-2024 indicate the crop area affected by drought, as shown in **Table 2-11**.

Table 2-10: Comparison of rainfall deficit year in Kerala

Rainfall in Kerala 2016 Vs 2023 Rain short fall (%)		
Month	2016	2023
June	8	67.5
July	39	2.75
August	45	85.75
Rainfall (mm)		
June-July-August	1,268.6 mm (Deficit - 466.80)	909.5 mm (Deficit - 825.5)

Table 2-11: Crop area affected due to drought for the period of 2019 to 2024 (Source: Department of Agriculture, Govt. of Kerala)

Crop type	Area affected (ha)
Arecanut	476.82
Banana	9,863.20
Coconut	2,115.23
Paddy	5,998.15
Tapioca	13.19

[36] https://sdma.kerala.gov.in/wp-content/uploads/2019/08/Drought-Situation-Assessment-2017-April.pdf

Table 2-12: List of historical drought events in Kerala

Year	Drought Severity	Impact on Agriculture	Impact on Water Resources	Other Impacts	Source
1983	Moderate	Reduction in crop yields	Water scarcity in many areas	Increased irrigation needs, economic losses	Kerala State Disaster Management Authority (2016). Drought Assessment Report.
2002	Severe	Significant crop yield reduction	Severe water scarcity	Increased migration, economic losses	Rajeevan, M., & Pai, D. S. (2017). Droughts in India: Climatic factors and observations.
2004	Moderate	Decline in agricultural productivity	Water shortages, especially in rural areas	Strain on public utilities, health issues	National Institute of Disaster Management (2017). Drought Management in India: A Case Study of Kerala.
2012	Severe	Major reduction in crop production	Critical water shortages	Economic stress, higher food prices	India Meteorological Department (2017). Annual Climate Summary.
2016	Moderate	Decline in agricultural productivity	Acute water shortages, especially in rural areas	Strain on public utilities, health issues	Kerala State Disaster Management Authority (2016). Drought Assessment Report.

2.1.1.7 Human Pandemics

The Case of the 2018 Kerala Floods:

The floods that ravaged Kerala in August 2018 resulted in widespread devastation, displacing hundreds of thousands of people and causing extensive damage to infrastructure and livelihoods. The inundation of water contaminated with sewage, debris, and animal carcasses created ideal breeding grounds for pathogens, increasing the risk of waterborne and vector-borne diseases. In the aftermath of the 2018 floods, Kerala experienced a surge in cases of waterborne diseases such as cholera, typhoid fever, and hepatitis A[37, 38]*. The consumption of contaminated water and food, as well as poor hygiene practices in overcrowded relief camps, contributed to the spread of these diseases among displaced populations.*

Additionally, there was an increase in vector-borne illnesses such as dengue fever and leptospirosis due to the proliferation of disease vectors in stagnant water and unsanitary conditions. The lack of access to clean water, sanitation facilities, and healthcare services further exacerbated the health risks faced by flood-affected communities.

Challenges in Disease Management:

The inundation of healthcare facilities and disruption of supply chains posed significant challenges to disease management efforts in the aftermath of the floods. Health authorities in Kerala had to mobilize resources rapidly to provide medical assistance, distribute hygiene kits,

[37] Thomas, E., Devassy, A. S., & Krishnan, N. (2019). Impact of the Kerala floods on communicable diseases: A study based on outbreak news reports. PLoS One, 14(8), e0220946.

[38] Mishra, A. (2022). Impact of Solid Waste and Health Effects during extreme floods. A case study from Kerala, India. Master's Thesis, University of Twente, Enscede, The Netherlands, pp.76.

and conduct public health awareness campaigns to prevent disease outbreaks.

Moreover, the spread of false information and rumors about disease transmission and prevention added to the complexities of disease management, necessitating clear communication strategies and community engagement initiatives.

Long-Term Health Impacts:

Beyond immediate disease outbreaks, the 2018 floods in Kerala had long-term health impacts on affected individuals and communities. Studies have documented the psychological toll of displacement, loss of livelihoods, and social disruption on mental health and well-being, highlighting the need for comprehensive psychosocial support and mental health services[39].

Additionally, the disruption of healthcare services and infrastructure, as well as the loss of healthcare personnel and resources, posed challenges to the delivery of essential healthcare services in flood-affected areas, exacerbating pre-existing health disparities and vulnerabilities.

Human pandemics triggered by post-natural hazard events, such as the 2018 floods in Kerala, underscore the complex interplay between environmental, social, and health factors. By understanding the dynamics of disease outbreaks in the aftermath of natural disasters and implementing proactive mitigation measures, authorities can better protect the health and well-being of vulnerable populations and build resilience to future challenges.

Based upon the field-survey of three settlements having characteristics for different geographical units (upland, midland, and lowland) in the Pamba basin, Kerala, the study[35] developed a post management working framework with support from KSDMA, which is based upon United Nation Environmental Programme (UNEP)' disaster management guidelines. The study also highlighted the role of Kudumbashree (a poverty eradication program in which a large group of women are employed), and Harit Karma Sena (Pan Kerala Volunteers Organization) in post 2018 floods in waste management and help in society clean-up, thus, controlling the vector-borne disease in the state.

2.1.2 Identification of Reporting/Monitoring Agencies

In Kerala, the monitoring and reporting of natural hazards such as floods, landslides, drought, and cyclones are facilitated by various governmental and non-governmental agencies tasked with disaster management and meteorological surveillance. These agencies play a crucial role in early warning, risk assessment, and response coordination to mitigate the impact of such hazards on communities.

***Kerala State Disaster Management Authority (KSDMA):** The KSDMA is the apex body in the State responsible for coordinating disaster preparedness, response, and mitigation efforts in Kerala. It develops disaster management plans and policy documents, and coordinates with relevant agencies during emergencies.*

***India Meteorological Department (IMD):** The IMD is the national meteorological agency responsible for weather forecasting, monitoring, and issuing warnings related to cyclones, heavy rainfall, and other meteorological events. The Regional Meteorological Centre (RMC) in Thiruvananthapuram provides localized weather forecasts and cyclone alerts for Kerala.*

***Kerala State Emergency Operations Centre (SEOC):** The SEOC serves as the*

[39] Nair, S., Joseph, A. P., & Krishnan, J. (2020). Health and well-being of communities affected by the 2018 Kerala floods: A qualitative study. International Journal of Environmental Research and Public Health, 17(7), 2462.

nerve center for monitoring and emergency response activities 24 x 7 and 365 days in a year. It coordinates with district-level disaster management authorities, police, fire services, DDMAs and other stakeholders to ensure timely response and assistance to affected areas.

District Disaster Management Authorities (DDMAs): *At the district level, DDMAs oversee disaster preparedness, response, and mitigation activities. They work closely with local administration, emergency services, and community organizations to address specific hazards and vulnerabilities within their jurisdictions.*

Kerala State Electricity Board (KSEB): *The KSEB monitors and manages hydroelectric dams and reservoirs in Kerala, which play a crucial role in flood control and water management during heavy rainfall events. It collaborates with disaster management authorities to regulate water release from dams and mitigate flood risks downstream.*

Indian National Centre for Ocean Information Services (INCOIS): *INCOIS provides oceanographic and meteorological information, including tsunami alerts and coastal hazard forecasts, to support disaster preparedness and response along the Kerala coast.*

These reporting and monitoring agencies collaborate closely to assess risks, issue timely warnings, and coordinate emergency response efforts to safeguard lives and property during natural hazards in Kerala. Their integrated approach to disaster management helps enhance resilience and reduce vulnerability to disasters in the state.

2.1.3 Development of Consolidated Spatial Database

The development of a consolidated spatial database represents a significant advancement in disaster management and mitigation efforts. By compiling data from various sources such as KSDMA memorandums on floods, landslides, cyclones, and droughts, as well as reports from the Geological Survey of India (GSI) on landslides and the Central Water Commission (CWS) on floods, this database provides a comprehensive overview of past disaster events and their spatial distribution. In addition to governmental reports, the database incorporates information gathered from research papers and other relevant reports, enriching the dataset with insights from academia and specialized studies. Furthermore, by leveraging the data available from EM-DAT (Emergency Events Database, https://www.emdat.be/), which is a global database on natural and technological disasters, the consolidated spatial database gains access to a wealth of information on disaster events worldwide, facilitating comparative analysis and learning from international experiences. The utilization of such a database holds immense potential for enhancing disaster preparedness, response, and recovery efforts. By providing spatially referenced data on past disaster occurrences, their impacts, and the factors responsible for their occurrence, decision-makers can gain valuable insights into vulnerable hotspots, risk factors, and trends over time. This, in turn, enables informed decision-making regarding land-use planning, infrastructure development, early warning systems, and resource allocation for disaster mitigation and response efforts.

Moreover, the consolidated spatial database serves as a valuable resource for researchers, policymakers, and other stakeholders involved in disaster risk reduction and management. It facilitates interdisciplinary research, supports evidence-based policymaking, and fosters collaboration among various stakeholders involved in disaster management at the local, regional, and national levels. In essence, the development of a *consolidated spatial database represents a crucial step towards building resilience to disasters, promoting sustainable development, and safeguarding communities and ecosystems against the adverse impacts of natural hazards. By harnessing the power of data and spatial analysis, it enables proactive and effective measures to mitigate risks, minimize losses, and build a safer and more resilient future for all.*

2.2 Data Collection from different Organizations in the State

The KSDMA plays a pivotal role in consolidating diverse datasets to comprehensively understand and mitigate the impacts of natural disasters. Here's an overview of the data consolidation process conducted by KSDMA:

RMSI data collection efforts from the KSDMA have yielded a comprehensive array of geospatial exposure data essential for our analysis and reporting (Table 2-13). This includes:

1. *Administrative Boundaries: Detailed maps and data outlining the administrative divisions in Kerala is crucial for analysis and disaster response planning.*
2. *Critical Infrastructure Buildings: Information on the location and specifications of critical infrastructure buildings, such as hospitals, schools, police stations, fire stations and cyclone shelters. This data helps in assessing the vulnerability and readiness of essential services during disasters.*
3. *Residential Buildings: Geospatial data on residential structures, including their distribution, and density. Unfortunately, this data (shared by KSREC) is partially available only for 5 districts in the Kerala state. The buildings footprint database is vital for evaluating potential impacts on populations and housing during various disaster events.*
4. *Transport Network: Detailed data on the transport infrastructure, including roads, bridges & flyovers, bus stations/depots, airports and railway lines and railway stations.*
5. *Historical Landslide and Flood Inventory: Records and maps of past landslide and flood events, which provide insights into areas historically susceptible to such hazards.*
6. *2018 and 2019 Flood and Landslide Damage Information: Specific data on percentage of damage, schools and hospital which includes affected areas and damage assessments.*
7. *Water Resource Data: Information on water bodies, rivers, reservoirs, and their management, which is crucial for flood risk assessment and water resource planning and flood control.*
8. *IMD Observed Station Rainfall Data: The team also received this data for a duration of past about 37 years.*
9. *Land Use Land Cover (LULC) Data for 2015-16 and 2020: Data on land use and land cover patterns across Kerala, which helps in understanding the human-environment interaction and its implications for change in disaster vulnerability.*

In addition to the geospatial data, we have gathered extensive damage and loss information from various reports published on the KSDMA website. These include:

1. *Disaster Memorandums and Reports: Official documents and memorandums detailing specific disaster events, responses, and recovery efforts. These reports provide critical insights into damages and estimated economical losses that affected buildings, infrastructure, agriculture sectors.*
2. *Research Reports and Published Research papers: Academic and technical reports and research papers that offer in-depth analyses of specific disasters, risk assessments, and*

recommendations for mitigation and preparedness.

By combining this extensive geospatial data with damage and loss reports, we created a consolidated geospatial major disaster database for Kerala state, which is used in developing NatCAT based disaster risk financing strategy.

2.2.1 DATA ANALYSIS AND VISUALIZATION BY RMSI

RMSI's team analyzed and visualized the spatial datasets using advanced Geographic Information System (GIS) technology. However, as with any massive data sets project, the team encountered a few challenges:

Topological Corrections: *The administrative boundaries dataset had several topological errors. A few corrections were made in Taluka code for three LSGs. These inaccuracies could lead to faulty analyses and visualizations. The team meticulously corrected these errors to ensure precise boundary definitions.*

Residential Data: *The residential data shared by KSREC was limited to only five districts and was of coarse resolution with missing attributes. Understanding the distribution and density of residential buildings across the entire state is essential for comprehensive risk assessment. To address this gap, the team decided to use RMSI in-house building footprint data, which offered a finer resolution and broader coverage.*

With these challenges addressed, the RMSI team could effectively analyze and visualize the spatial datasets.

2.2.2 HAZARD EVENT DATA CONSOLIDATION PROCESS

2.2.2.1 Flood Events

In recent years, Kerala has experienced severe flood events, necessitating comprehensive data consolidation to understand the patterns, causes, and impacts of these occurrences. The consolidation process involves gathering information from various sources, including the KSDMA memorandums, CWC reports, NRSC database, GSI and published literature. The aim is to create a unified hazard event catalogue that serves as a valuable resource for research, analysis, and decision-making.

Official records and reports from the KSDMA provide detailed accounts of flood events, including their dates, locations, severity, and impacts. Reports from CWC offered hydrological data, river flow measurements, rainfall statistics contributing to a comprehensive understanding of flood dynamics. Academic papers, articles, and studies published in scientific journals provided valuable insights into flood events, their causes, and potential mitigation strategies.

Collected data from different sources are compiled into a centralized database, ensuring consistency and uniformity in data formats and structures. Standardization of data involves aligning terminology, units of measurement, and data classifications to facilitate seamless integration and analysis.

2.2.2.2 Landslide Events

Kerala's unique topography and climatic conditions make it particularly vulnerable to landslides, necessitating thorough data consolidation to grasp the extent, causes, and impacts of these events. The consolidation process drawn from various sources such as the KSDMA reports, geological surveys, and academic research. KSDMA reports offer detailed accounts of landslide occurrences, including specific locations, the extent of damage, and the immediate impacts. Geological surveys provided critical data on soil stability, rock formations, and slope analyses, which are essential for understanding the underlying causes of landslides. Academic research contributed valuable insights into landslide triggers, historical data, and risk assessments. This *diverse data is then compiled into a centralized database, ensuring consistency in data formats and structures. Standardization of geological terms, measurements, and classifications is crucial for seamless integration and analysis. Rigorous validation processes are employed to verify the accuracy, reliability, and completeness of the collected data, with quality assurance measures in place to identify and rectify any errors or inconsistencies, ensuring the dataset's integrity and usability.*

2.2.2.3 Tropical Cyclones

Tropical cyclones, although less frequent in Kerala compared to other natural hazards, have the potential to cause significant damage, making comprehensive data consolidation essential for understanding their patterns, causes, and impacts. This process involves collecting data from sources such as IMD reports, KSDMA impact reports, and scientific publications. IMD reports provide detailed information on cyclone tracks, wind speeds, and rainfall data, which are critical for understanding the meteorological aspects of cyclones. KSDMA impact reports offered insights into the affected areas, population displacement, and economic losses caused by cyclones. Scientific publications contributed to a deeper understanding of cyclone patterns, climatic influences, and potential mitigation measures. The collected data is compiled into a centralized database, ensuring consistency in data formats and structures. Standardization of meteorological terms, measurement units, and impact classifications facilitates seamless integration and analysis. Rigorous validation processes are employed to verify the accuracy, reliability, and completeness of the collected data, with quality assurance measures in place to identify and rectify any errors or inconsistencies, ensuring the dataset's integrity and usability.

2.2.2.4 Droughts

Droughts in Kerala necessitate a focus on long-term climatic data and water resource management, requiring comprehensive data consolidation to understand the patterns, causes, and impacts. This process involves gathering data from sources such as IMD and KSDMA reports, agricultural and water resource departments, and research studies. IMD and KSDMA reports provided detailed information on rainfall deficits, temperature anomalies, and official drought declarations Research studies contributed to a deeper understanding of drought trends, climatic factors, and potential adaptation strategies.

RMSI team obtained district-level crop area and yield data from the Crop Production Statistics Information website (https://aps.dac.gov.in/APY/Index.htm). However, for our comprehensive drought assessment project in the state, it is imperative that we procure taluk-level crop information as well. The collected data is compiled into a centralized database, ensuring consistency in data formats and structures. Standardization of terms related to drought conditions, measurements, and impact assessments facilitates seamless integration and analysis. Rigorous validation processes are employed to verify the accuracy, reliability, and completeness of the collected data, with quality assurance measures in place to identify and rectify any errors or inconsistencies, ensuring the dataset's integrity and usability.

Table 2-13: List of exposure data layers collected from different sources

Exposure layer name	Data Source	Data Gap and Filling Approach
Administrative Boundary		
District Boundary	KSDMA	
Taluka Boundary	KSDMA	
LSG Boundary	KSDMA	In Palakkad district, Sholayoor, Pudur and Agali LSGs in Attapati Taluka were missing with their updated Taluka code. RMSI team has identified this error and filled with latest Taluka code T09007
Village Boundary	KSDMA	
Ward Boundary	KSDMA	
Municipality Boundary	KSDMA	
Corporation ward Thrissur	KSDMA	
Corporation ward Trivandrum	KSDMA	
Corporation ward Kannur	KSDMA	
Corporation ward Kochi	KSDMA	
Corporation ward Kollam	KSDMA	
Corporation ward Kozhikode	KSDMA	
Housing Sector (Building Footprint)		
Low, medium and high-rise building footprints	KSREC	Partial building footprint data for five districts—Ernakulam, Kollam, Kannur, Thiruvananthapuram, and Kozhikode—was provided by KSREC. However, significant gaps were identified in both the building footprint data and their attributes. To address these gaps, the RMSI team enriched the data by adding essential attributes such as building construction type, number of floors, and construction cost etc. This effort was extended to not only the provided districts but also to cover the entire state of Kerala comprehensively.
Government Buildings		
Govt. Offices	KSDMA	
Panchayat Offices	KSDMA	
Taluka Head Quarter	KSDMA	
District Head Quarter	KSDMA	
Revenue office	KSDMA	
Ration Shop	KSDMA	
Police Stations	KSDMA	
Fire Stations	KSDMA	
Cyclone Centre	KSDMA	

Exposure layer name	Data Source	Data Gap and Filling Approach
Schools (Govt., Technical and Private)	KSDMA	
Hospitals (Govt. and Private)	KSDMA	
Transport Network		
Roads	KSDMA	
Airport	KSDMA	
Railway Line	KSDMA	
Railway Station	KSDMA	
District Headquarters	KSDMA	
Taluk Headquarters	KSDMA	
Bridges/Flyovers	KSREC	RMSI received the point locations of bridges without any associated attribute data. The RMSI team mapped these as line features representing bridges and flyovers, adding the appropriate attribute information to ensure comprehensive data representation. We approached PWD Kerala several times through RKI. however, no data were shared.
Bus Station	KSREC/KSDMA	
Demographic (Population and Household)		
Census 2011 population/households at village level	KSDMA	RMSI projected 2011 census population to 2023. Few villages were found with zero population and they have been filled using RMSI in house census population data.
Land use/Land cover		
LULC (2015-2016) and 2020	KSREC/KSDMA	We used LULC 2020 data

3

Collection of Information on Economic, Financial, and Human Losses

3 Collection of Information on Economic, Financial, and Human Losses

3.1 Insurance losses

Insurance plays an important role in contributing to the economic development as it indemnifies the losses of the insured individuals and corporates against the insured perils – protecting the various kinds of risks (property, health, life, and liability). It also provides the long- term funds for infrastructure development at the same time strengthening the risk-taking ability of the individual, state, and or country.

For developing insurance products, understanding the financial and economic losses caused by natural disasters is essential. In Kerala state, where the frequency and severity of disasters pose significant challenges, it is imperative to develop comprehensive databases of financial and economic losses. This chapter outlines key actions review of damage assessment reports, insurance records, and other relevant sources in developing a consolidated database of such losses. The resulting database is being used as a vital dataset for calibrating probabilistic catastrophic risk models and informing NatCAT based disaster risk financing strategy and parametric-insurance prototype products for the Kerala state.

Increasing Natural Catastrophic Losses:

Climate risk poses numerous challenges causing rising natural catastrophic losses and also disaster risk exposures in our country. As per Swiss report 2022-23, over 70% of the natural catastrophic losses are mainly caused by increasing weather risk volatility and secondary perils. Further, increasing urbanization, especially in tier 2 and tier 3 cities due to rural to urban migration and infrastructure developments escalates the disaster risk exposures leading to increasing property losses. As per Swiss-Re report 2023, natural hazards catastrophic losses are rapidly increasing along with widening of Nat-Cat Protection Gap. From Figure 3.1, it can be seen that the natural catastrophic losses have almost doubled in every 5 years, surpassing the annual average of US$260 billion globally. As per latest Swiss Re, the protection gap in India is over 95% indicating only 5% of the natural catastrophic losses are protected through insurance, causing a huge financial liability to the governments burdening the already stressed development budgets.

Low *Insurance* Penetration in Kerala State:

A large number of individuals in the state do not have any type of property insurance to protect their houses and households from the natural disasters. Our analysis (detailed in Component-3 Report) indicates that less than 6% of the people do have some kind of insurance. However, even among those who are insured, more than 90% of them have taken insurance due to bank loan and their coverages / sum insured is highly inadequate as bank covers only the outstanding loan amount, not the market value of their house/ property. 2018 Kerala floods.

The 2018 Kerala floods led to substantial insurance claims, highlighting the economic impact of the disaster. The total claims surpassed Rs 1,500 crore, according to The Indian Express, although not all these claims may result in cash payouts. State-run United India Insurance, the most active insurance firm in Kerala, faced the largest burden, with Rs 700 crore *in claims to settlement[40]. Initial estimates of general insurance claims amounted to Rs 10 billion (approximately $137 million), which is lower than the claims during the Chennai floods in 2015, indicating lower insurance penetration in Kerala households. Speaking at the Insurance Advisors Meet in Chennai, CMD (K B Vijay Srinivas, joint charge) United India Insurance Company, stated that his company received 5,000 claims worth Rs 3.5 billion [41] . Another discussion with Underwriters (personal communication) informs that total economic losses were to the tune of $4.0 billion, out of which insured losses were about 0.47 billion. Overall, insurance claims from the 2018 floods (including landslide damage), which caused economic losses estimated at $3 billion, approached Rs 2,000 crore (approximately $273.2 million, the majority have been from the motor insurance, driven by the fact numerous cars and motorcycles were submerged in water for days after the flooding event), with public sector insurers bearing the brunt more than private companies[42].*

3.2 Projected damage and losses to current year

As per project objective, the projected damage and losses outlined in the geo-spatial catalogue were computed using monetary values denominated in US dollars, which have been meticulously adjusted for inflation. This adjustment process adheres to the standardized methods endorsed by EM-DAT, the Emergency Events Database, ensuring consistency and accuracy in the estimation of economic impacts. EM-DAT employs a robust adjustment formula that relies on the OECD Consumer Price Index (CPI)[43]. This index serves as a reliable benchmark for tracking changes in the general price level of goods and services over time across member countries of the Organization for Economic Co-operation and Development (OECD). By incorporating the CPI into the adjustment process, EM-DAT ensures that monetary values are appropriately scaled to reflect changes in purchasing power and inflation rates[44].

The application of the EM-DAT adjustment formula enables analysts and researchers to account for the effects of inflation when comparing economic data across different time periods and geographical regions. By standardizing monetary values to a common base year and currency, typically US dollars, EM-DAT facilitates meaningful comparisons and accurate assessments of disaster-related economic losses. In summary, the utilization of the EM-DAT adjustment formula, grounded in the OECD Consumer Price Index, enhances the reliability and comparability of economic loss estimates within the database. This rigorous methodology underscores EM-DAT's commitment to providing stakeholders with high-quality, standardized data for informed decision-making in disaster risk management and humanitarian response efforts.

Loss adjustments have been calculated based on EM-DAT using global and Indian CPI values. Upon reviewing the adjusted values, it appears that the EM-DAT adjusted values are significantly lower for India disaster events. This discrepancy is from the limitations of adjusting EM-DAT data solely based on US inflation (CPI values), which does not fully account for Indian high inflation data. And also, we

[40] https://www.financialexpress.com/business/industry-kerala-floods-impact-insurance-companies-receive-over-rs-1500-crore-in-claims-1311900/

[41] https://www.business-standard.com/article/companies/kerala-floods-rs-10-bn-claim-shows-insurance-penetration-low-in-the-state-118082800646_1.html

[42] https://www.reinsurancene.ws/insurance-claims-from-kerala-india-floods-surpass-us273-million/#:~:text=Insurance%20claims%20from%20the%20severe,likely%20to%20hit%20public%20sector

[43] https://data.oecd.org/chart/6RMa

[44] https://doc.emdat.be/docs/protocols/economic-adjustment/

computed adjustments using Indian CPI which is more reasonable than US CPI values in context of Kerala State.

3.3 Supporting Probabilistic Catastrophic Risk Models

The resulting database is being used for calibrating probabilistic catastrophic risk models. By providing robust data on the financial impacts of past disasters, these models can better estimate the potential magnitude and frequency of future events. Moreover, the database is facilitating scenario analysis and risk assessment, enabling stakeholders to identify vulnerabilities, prioritize mitigation efforts, and allocate resources effectively.

In conclusion, the development of a consolidated database of financial and economic losses caused by natural disasters is crucial for developing disaster risk financing strategy as well as parametric products. By reviewing damage assessment reports, insurance records, and other sources, we could gain valuable insights into the economic impacts of past disasters. This database, will enable stakeholders in understanding of disaster risk and resilience, ultimately contributing to more effective strategies for mitigating the impacts of future disasters in Kerala.

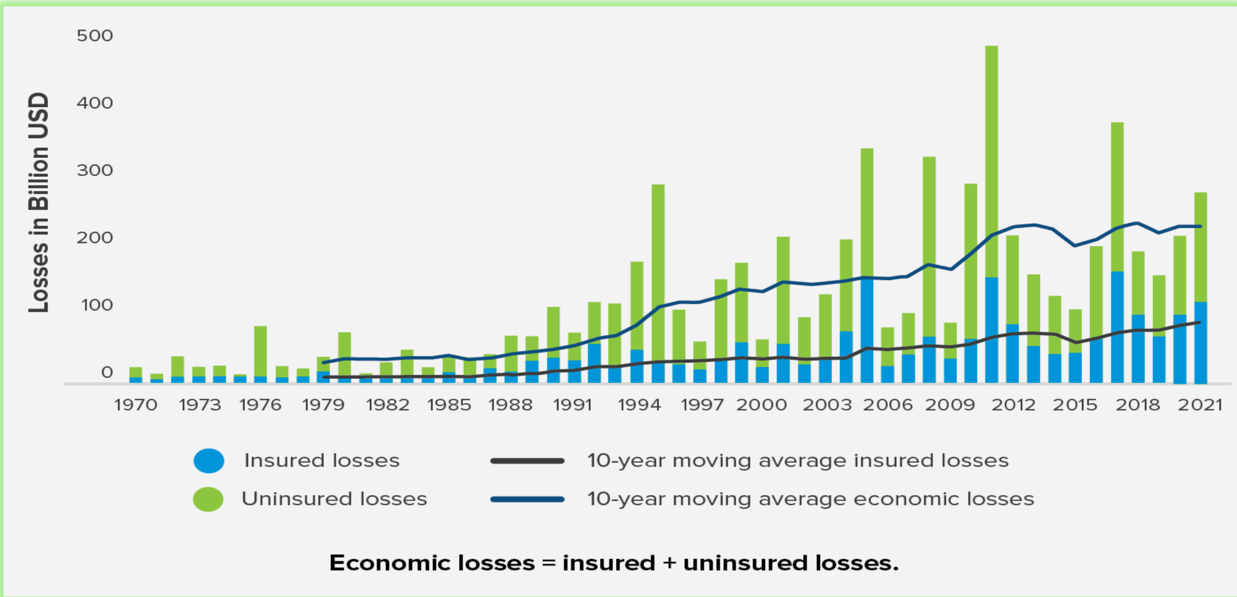


Figure 3-1: Increasing the Nat-Cat Protection Gap (1970-71 to 2021-22) at India Level

Table 3-1: Segment wise Contribution of Kerala State to Gross Direct Premium (in %)

	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23
Fire	6.89	6.58	5.83	5.49	4.57	5.08	6.06	7.00	6.53	6.54
Engineering	1.10	1.27	1.05	1.06	0.71	0.61	0.66	0.61	0.76	0.88
Motor Own Damage	39.66	36.00	36.38	40.03	35.87	32.28	30.88	29.34	28.58	29.04
Motor Third Party	43.68	47.60	48.38	45.92	52.83	53.66	56.19	55.99	57.22	56.24
Liability Insurance	0.68	0.58	0.64	0.46	0.49	0.77	0.51	0.66	0.60	0.68
Crop Insurance	0.62	0.56	0.71	1.10	0.63	2.68	1.34	1.77	1.98	2.65

Note: Numbers given in the above table indicates the share of premium of the Kerala state to the total premium of the fire premium portfolio.

We can see from the above table that less than 6% are insured. Even among the corporates also, many do not have adequate property insurance coverage. Table 3-2 provides the extent of Insured losses from major catastrophic events in Kerala and other States.

Table 3-2: Extent of Insured losses in respect of Major Natural Catastrophic Events in Kerala & other States

Year	Disaster Type	Location	Economic Loss ($ Bn)	Insured Loss ($ Bn)	Insured as % of Total
1991	Flood	Mumbai, Kerala, Gujarat	0.1	0.0	48
2005	Flood	Multiple States	3.3	0.8	25
2006	Flood	Multiple States	3.4	0.4	12
2009	Flood	Karnataka, Andhra Pradesh, Maharashtra	2.2	0.1	2
2013	Flood	Multiple States	1.1	0.5	45
2015	Storm	Multiple States	0.9	0.1	12
2015	Drought	Multiple States	3.0	0.4	13
2018	Flood	Kerala State	3.0-4.0	0.27-0.47	9-12
2019	Flood	Multiple States	10.0	0.2	2
2020	Flood	Multiple States	7.5	0.8	11

Source: EM-DAT; SBI Research, Reinsurance News, personal communication, etc.

4

Geo-Referenced Catalogue of Historical Major Events

4 Geo-Referenced Catalogue of Historical Major Events

4.1 EM-DAT format

EM-DAT, the Emergency Events Database, is a globally recognized repository of disaster-related data maintained by the Centre for Research on the Epidemiology of Disasters (CRED)[45]. Its data format and structure are meticulously designed to capture comprehensive information on various aspects of disasters, including their types, impacts, and responses.

Importance of EM-DAT Data Format:

Standardization: EM-DAT follows a standardized data format, ensuring consistency and comparability across different disaster events and geographical regions. This standardization facilitates reliable analysis, research, and decision-making processes.

Comprehensive Information: The data format of EM-DAT encompasses a wide range of parameters, including disaster type, location, magnitude, economic losses, and human casualties. This comprehensive information enables stakeholders to gain a holistic understanding of disaster events and their impacts.

Accessibility: EM-DAT provides accessible data through its online platform, allowing researchers, policymakers, and humanitarian organizations to access up-to-date information on past disasters. This accessibility promotes transparency, collaboration, and evidence-based decision-making in disaster risk management and response efforts.

Longitudinal Analysis: By maintaining historical data on disasters spanning several decades, EM-DAT facilitates longitudinal analysis and trend identification. Researchers can analyze changes in disaster frequency, severity, and impacts over time, aiding in the development of proactive mitigation and adaptation strategies.

Global Perspective: EM-DAT aggregates data from various sources worldwide, providing a global perspective on disaster trends and patterns. This global dataset enhances understanding of cross-border disaster risks and fosters international cooperation in disaster preparedness and response.

In summary, the data format of EM-DAT plays a crucial role in organizing, standardizing, and disseminating information on disasters. Its importance lies in promoting data-driven decision-making, facilitating research and analysis, and enhancing global collaboration in disaster risk reduction and humanitarian assistance efforts.

4.2 Compilation of major hazard events in Kerala

4.2.1 Key Parameters Included in the Catalogue

The compilation of a disaster catalogue involves the meticulous gathering and organization of key parameters that provide critical insights into the magnitude, impact, and aftermath of natural disasters. Each attribute plays a significant role in understanding the severity of the event and its implications for affected communities and infrastructure. Here's a brief note highlighting the importance of these key parameters:

In summary, the compilation of these key parameters in the disaster catalogue provides a comprehensive understanding of the event's impact, facilitating effective response, recovery, and risk mitigation efforts.

[45] https://www.emdat.be/

4.2.2 ANALYSIS OF COMPILED HAZARD EVENT DATA

Kerala State has faced recurrent and devastating flood and landslide events over the past decade. These natural disasters have caused extensive damage to housing, agriculture, infrastructure, and have resulted in significant loss of life. This report synthesizes detailed damage statistics for key events from 2012 to 2021 from KSDMA memorandums highlighting the impact on various districts and the broader economic implications.

Table 4-1: The key parameters used in geo catalogue

Key Parameter	Importance
Disaster ID	Provides a unique identifier for each disaster event, facilitating easy tracking and reference.
Disaster Type and Subtype	Classifies the nature and specific characteristics of the disaster, enabling categorization for analysis and planning.
Event Name	Offers a descriptive title for the disaster event, aiding in identification and communication.
Location, Latitude, and Longitude	Pinpoints the geographic coordinates of the disaster, crucial for mapping, spatial analysis, and targeted response.
Origin	Identifies the cause or source of the disaster, informing mitigation strategies and risk assessment.
Funds Contribution	Tracks financial assistance and resource allocation for disaster response and recovery efforts.
Magnitude/Category	Quantifies the intensity or severity of the disaster event, aiding in comparative analysis and risk assessment.
River Basin	Indicates the geographical area affected by the disaster, especially relevant for hydrological events.
Date	Records the timing of the disaster event, essential for chronological analysis and trend identification.
Casualties and Affected Population	Documents the human impact of the disaster, guiding humanitarian response and assistance efforts.
Infrastructure and Property Damage	Assesses the extent of damage to buildings, roads, and other critical infrastructure, informing reconstruction.
Agriculture and Livestock Impact	Measures the impact on agricultural land and livestock, crucial for food security and livelihood restoration.
Economic Loss	Quantifies the financial impact of the disaster, aiding in resource mobilization and recovery planning.
Consumer Price Index (CPI)	Adjusts economic loss figures for inflation, ensuring accurate and comparable analysis over time.
Total Economic Loss (INR Crore)	Quantifies the overall financial impact of the disaster in Indian Rupees, providing insights into the economic burden.
Total Economic Loss (USD $M)	Measures the total financial impact of the disaster in US dollars, facilitating international comparisons.
Total Economic Loss Adjusted (USD $M)	Adjusts the total economic loss figures for inflation and currency exchange rates, ensuring accuracy over time.

Key Parameter	Importance
Reconstruction Costs (INR Crore)	Estimates the costs associated with rebuilding and restoring infrastructure and property affected by the disaster.
Reconstruction Costs (USD $M)	Quantifies the reconstruction costs in US dollars, aiding in resource allocation and financial planning.
Reconstruction Costs Adjusted (USD $M)	Adjusts the reconstruction costs for inflation and currency fluctuations, providing accurate financial projections.
Insured Damage (INR Crore)	Represents the portion of the economic loss covered by insurance policies, mitigating financial losses for stakeholders.
Insured Damage (USD $M)	Quantifies the insured damage in US dollars, providing insights into the extent of insurance coverage for the disaster.
Insured Damage Adjusted (USD $M)	Adjusts the insured damage figures for inflation and currency exchange rates, ensuring accurate valuation over time.
Total Damage (INR Crore)	Estimates the total damage caused by the disaster in Indian Rupees, encompassing both insured and uninsured losses.
Total Damage (USD $M)	Measures the total damage in US dollars, facilitating international comparisons and financial assessments.
Total Damage Adjusted (USD $M)	Adjusts the total damage figures for inflation and currency fluctuations, providing accurate financial assessments.

4.2.2.1 2012 Floods and Landslides:

In 2012, Kerala experienced severe flood and landslide events that notably impacted the districts of Kannur, Kozhikode, and Wayanad. Approximately 600 houses were damaged in Kannur alone. The total death toll reached 15, with Kozhikode and Ernakulam experiencing the highest fatalities. Agricultural land was extensively damaged, particularly in Kozhikode, affecting 55% of the area's farmland. The reconstruction costs and economic losses were highest in Kozhikode and Kannur, underlining the financial strain on the affected regions. Damage statistics and economic losses of 2012 flood and landslides have given in Figure 4-1 to Figure 4-4.

4.2.2.2 2013 Floods and Landslides:

The 2013 events saw severe housing damage in Alappuzha and Thiruvananthapuram districts (Figure 4-5). The total number of deaths were 146, with Alappuzha and Thrissur bearing the brunt. Pathanamthitta, Kottayam and Palakkad suffered major agricultural losses. The number of fatalities, agriculture land affected due to this event has given in Figure 4-6 and Figure 4-7. The economic reconstruction losses were significant in Thiruvananthapuram and Alappuzha districts, respectively (Figure 4-8).

4.2.2.3 2014 Floods and Landslides (April-May):

In 2014 (April-May), floods and landslides caused substantial damage to housing in Thiruvananthapuram and Wayanad. The highest number of fatalities occurred in Thiruvananthapuram (7 deaths) and Kozhikode (5 deaths). Extensive agricultural damage was reported in Thiruvananthapuram, with total economic losses being particularly high in this district. Damage statistics and economic losses of *this event has given in Figure 4-9 to Figure 4-12.*

4.2.2.4 2014 Floods and Landslides (June-September):

The 2014 (June-September) events resulted in severe damage to housing in Thiruvananthapuram, Kollam, Idukki and Kozhikode (Figure 4-13). The death toll was highest in Wayanad and Idukki, with significant fatalities reported (Figure 4-14). Agricultural land was heavily impacted in Alappuzha (Figure 4-15). Idukki and Malappuram reported the highest economic losses (Figure 4-16).

4.2.2.5 2018 Floods and Landslides (June-July):

In 2018 (June-July), extensive flooding and landslides affected multiple districts, with Kozhikode, Pathanamthitta and Thiruvanthapuram being the most impacted with house damages (Figure 4-17). Kozhikode alone saw around 2,518 houses damaged. The fatalities were highest in Kannur and Kozhikode, which recorded 22 and 21 deaths, respectively (Figure 4-18). Kottayam and Alappuzha faced significant agricultural losses (Figure 4-19). The economic impact was severe, with Kottayam and Ernakulam incurring the highest economic losses (Figure 4-20).

4.2.2.6 2018 Floods and Landslides (August):

In 2018 (August), extensive flooding and landslides affected multiple districts, with highest houses damaged in Pathanamthitta, Thrissur and Alappuzha. Ernakulam alone saw around 1,500 houses damaged (Figure 4-21). The fatalities were highest in Thrissur, Ernakulam and Idukki, which recorded 72, 58, and 54 fatalities, respectively (Figure 4-22). Pathanamthitta and Alappuzha faced significant agricultural losses (Figure 4-23). The economic impact was severe, with Pathanamthitta and Thrissur incurring the highest economic losses (Figure 4-24).

4.2.2.7 2019 Floods and Landslides:

The year 2019 saw severe damage, particularly in Malappuram and Kozhikode, where hundreds of houses were damaged (Figure 4-25). The total death toll was 125, with Malappuram experiencing significant fatalities (~50%) (Figure 4-26). Kannur had the highest agricultural land damage (Figure 4-27), and both Thrissur and Malappuram faced substantial economic losses (Figure 4-28).

4.2.2.8 2021 Floods and Landslides

The 2021 events continued the trend of significant impact, with Kottayam and Idukki experiencing severe housing damage (Figure 4-29). The fatalities were highest in Kottayam and Idukki, underscoring the human cost of these disasters (Figure 4-30).

District wise spatial distribution of economic loss maps of all these events have given in Figure 4-34 to Figure 4-40

4.2.2.9 Total event catalogue analysis:

Kerala's recurring floods and landslides have resulted in significant damage and economic loss, particularly in the districts of Thrissur, Malappuram, Alappuzha Pathanamthitta and Thiruvananthapuram. Each year, these natural disasters lead to extensive damage to housing, agriculture, and infrastructure, coupled with considerable human fatalities (Figure 4-31 and Figure 4-32). The financial toll underscores the critical need for robust disaster management, preparedness, and recovery planning to support affected communities and mitigate future risks. Enhanced infrastructure resilience, early warning systems, and community-based disaster risk reduction initiatives are essential to addressing the challenges posed by these recurring natural disasters. In the compiled event catalogue flood, landslide, drought and cyclone hazards have been assigned with codes of FLD, LS, DRT and CYC, respectively with their year of occurrence (Figure 4-33). If there are *multiple events in the same year, they have been assigned with serial numbers. The compiled catalog has been provided in both Excel and geospatial formats. For geospatial representation, RMSI has developed a geodatabase that includes:*

- *A location-specific shapefile for the landslide inventory.*
- *Flood and landslide events mapped at the district level (where available).*
- *Flood, cyclone, and drought events primarily represented at the state level.*

Additionally, cyclone tracks compiled from IMD and KSDMA have been incorporated into the geodatabase for comprehensive analysis.

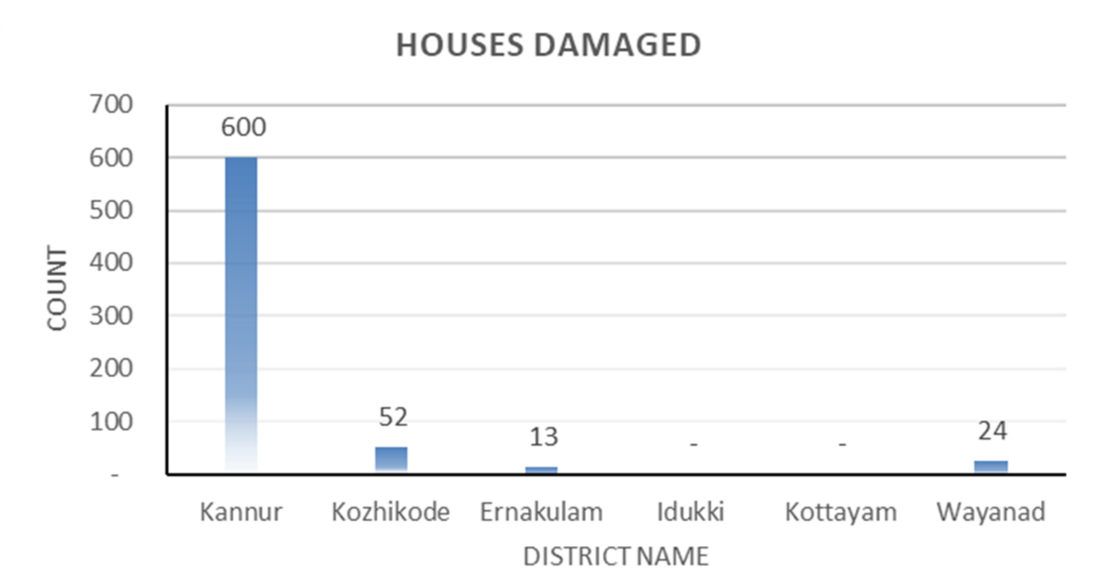


Figure 4-1: District wise number of houses damaged due to 2012 floods and landslides

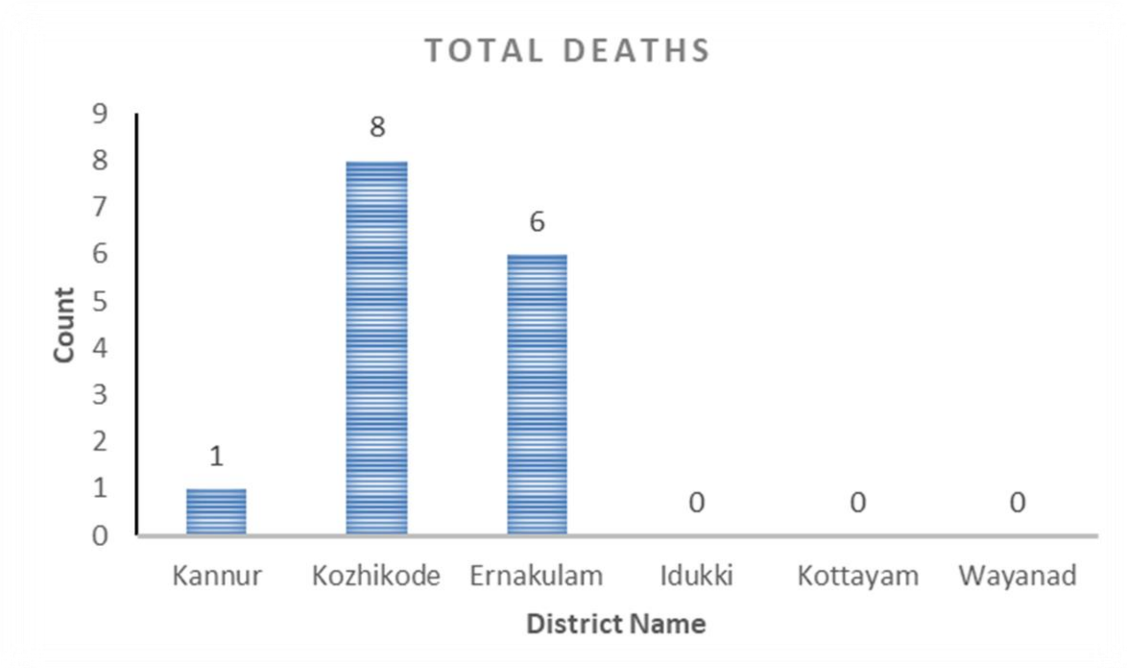


Figure 4-2: District wise fatalities due to 2012 flood and landslides

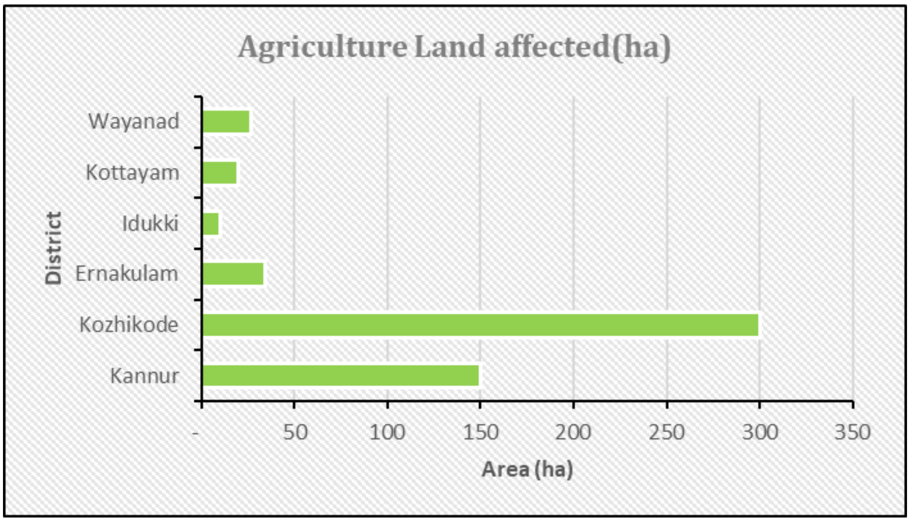


Figure 4-3: Agriculture land affected due to 2012 floods and landslides

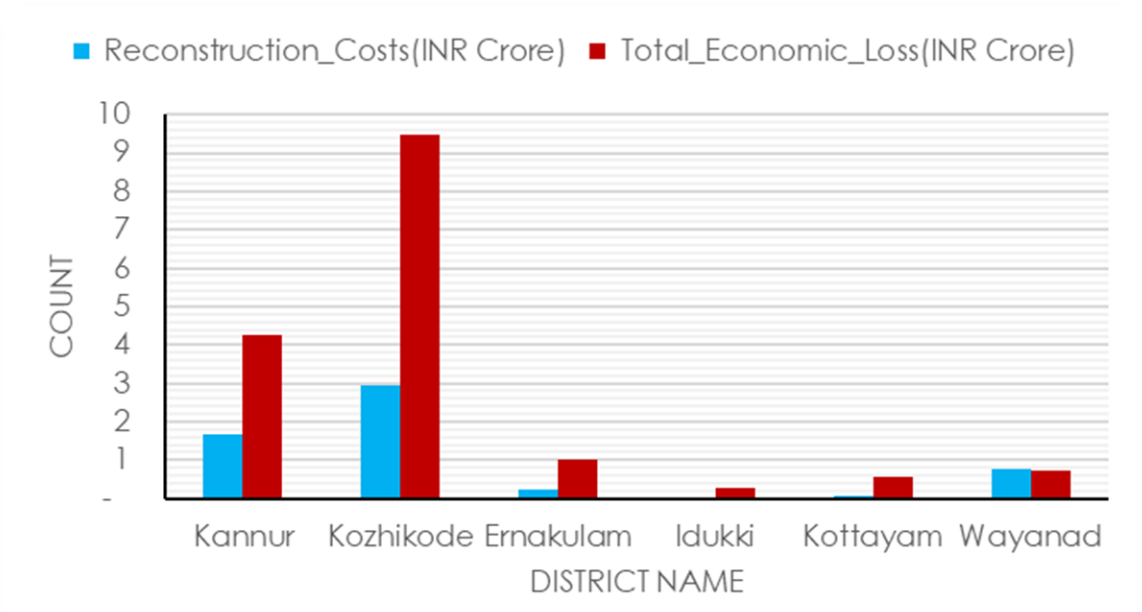


Figure 4-4: Total economic and reconstruction costs for different districts due to 2012 flood and landslides

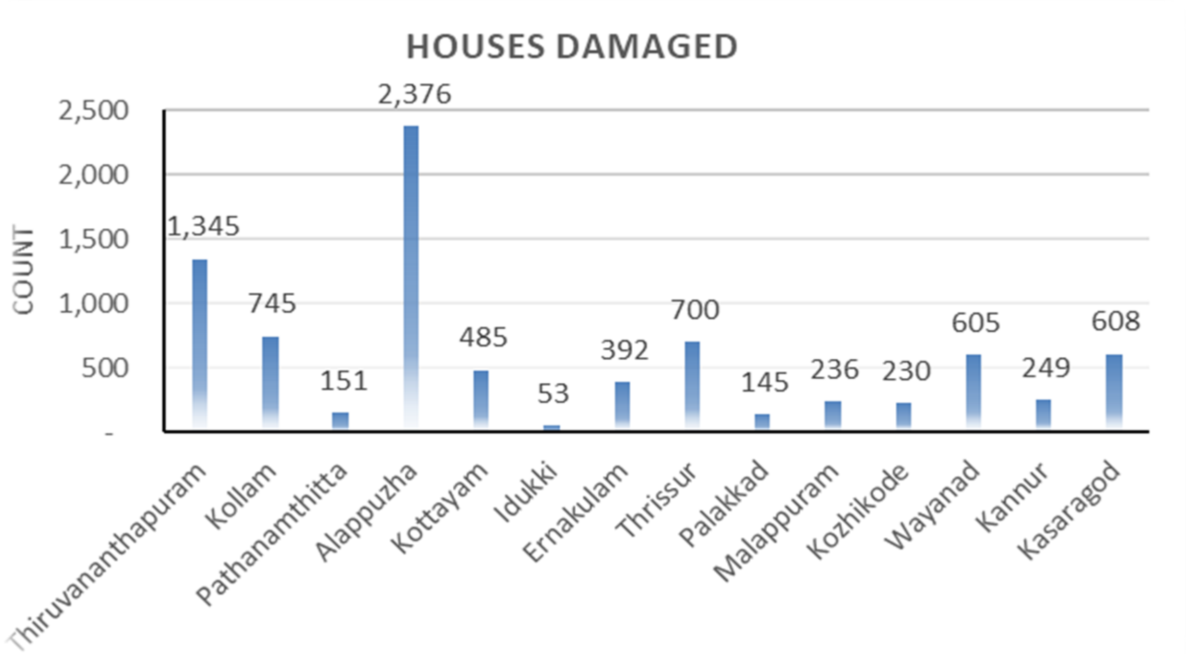


Figure 4-5: District wise number of houses damaged due to 2013 floods and landslides

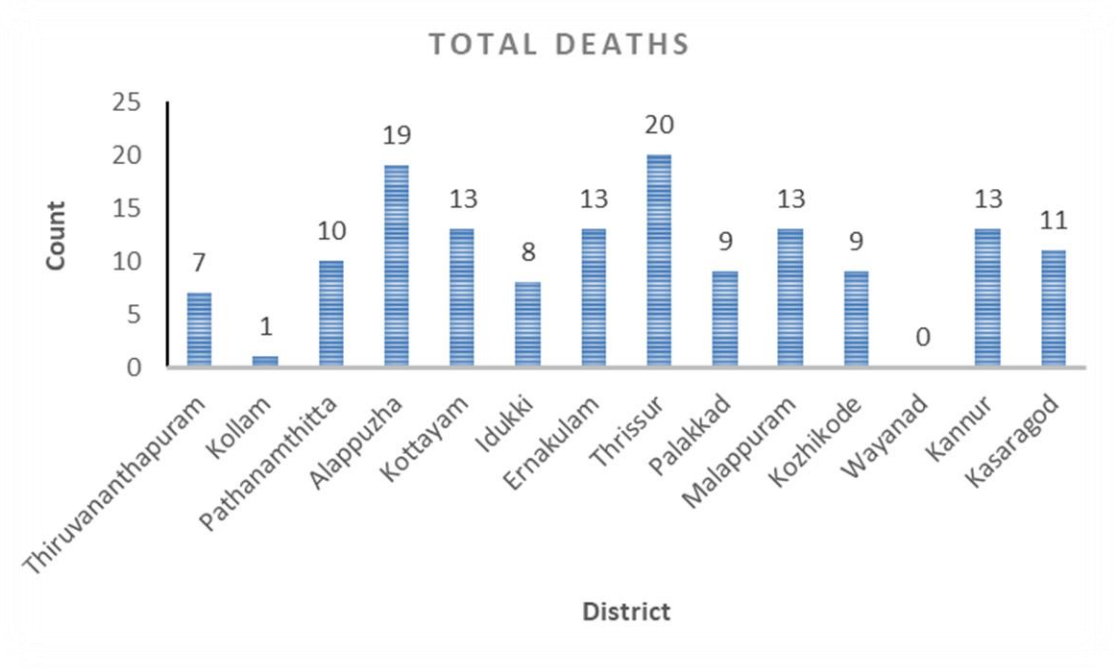


Figure 4-6: District wise fatalities due to 2013 flood and landslides

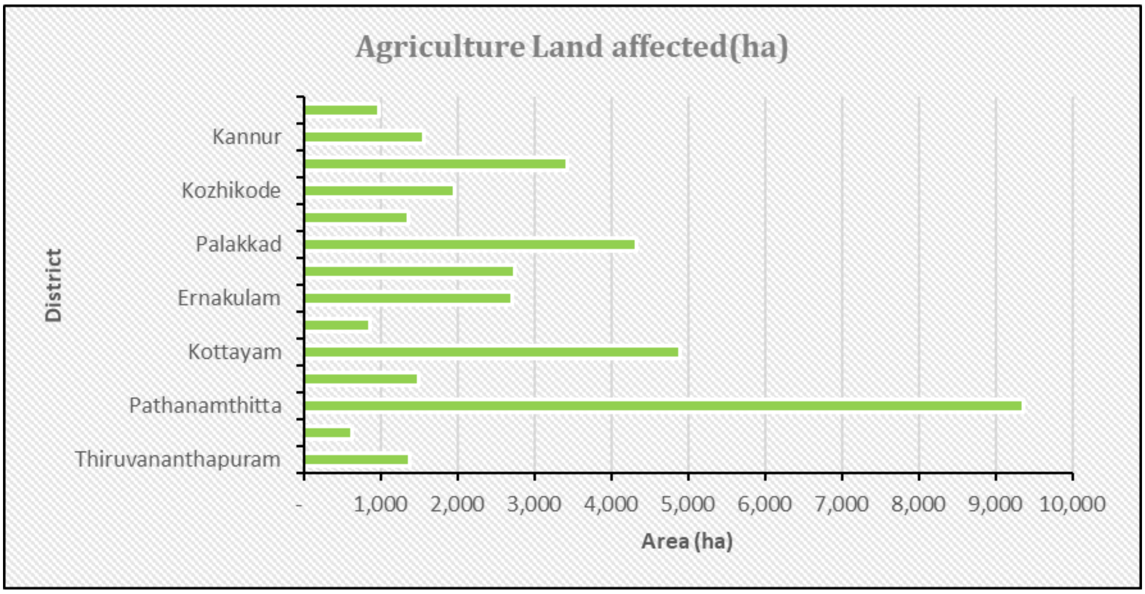


Figure 4-7: Agriculture land affected due to 2013 floods and landslides

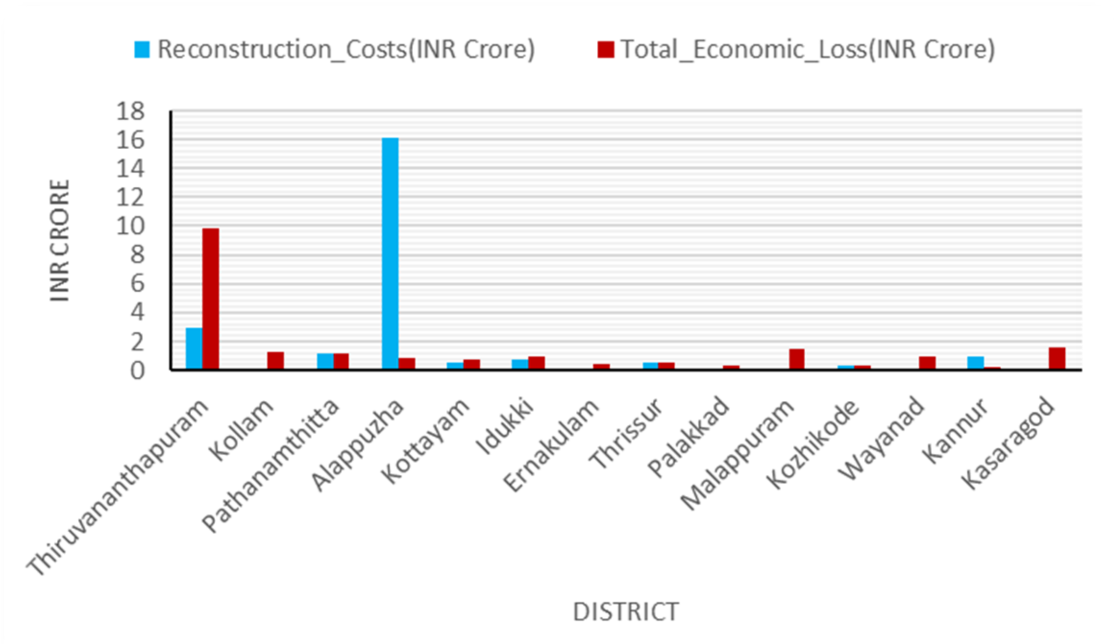


Figure 4-8: Total economic and reconstruction costs for different districts

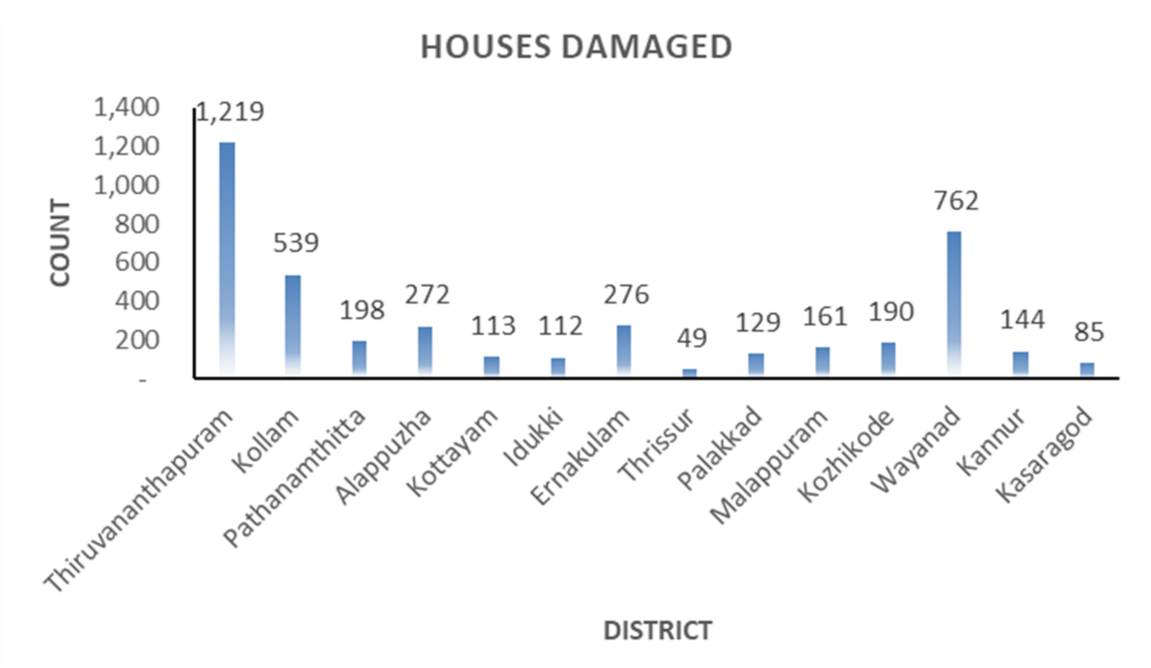


Figure 4-9: District wise number of houses damaged due to 2014 floods and landslides (April-May)

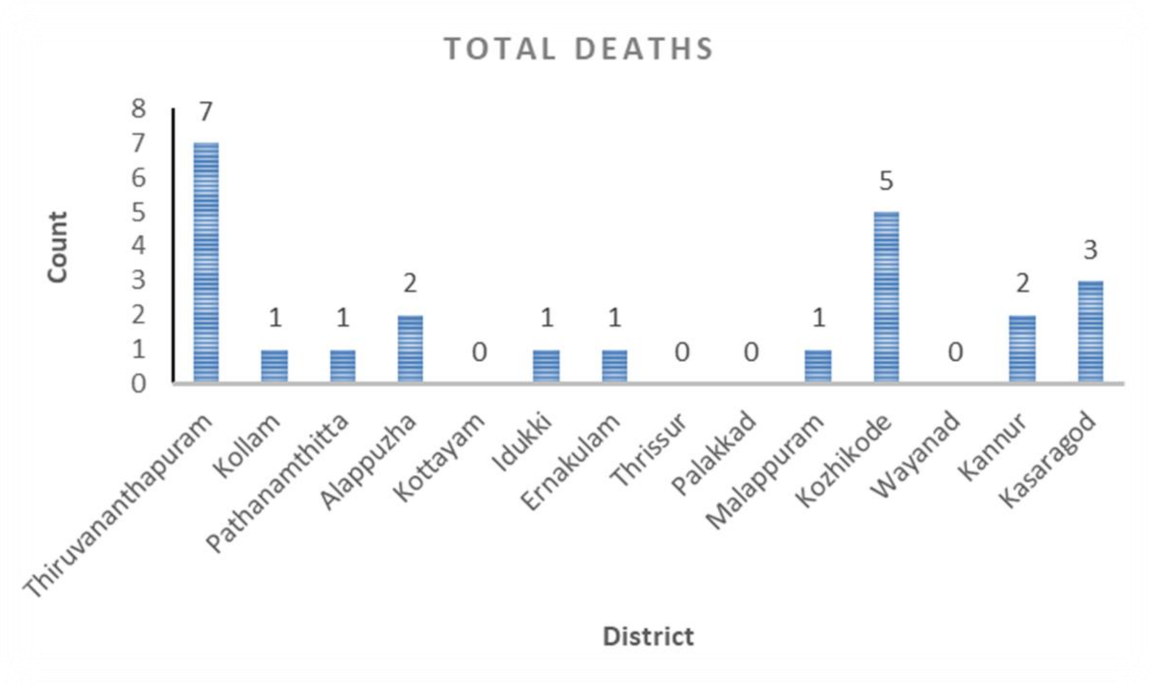


Figure 4-10: District wise fatalities due to 2014 flood and landslides (April-May)

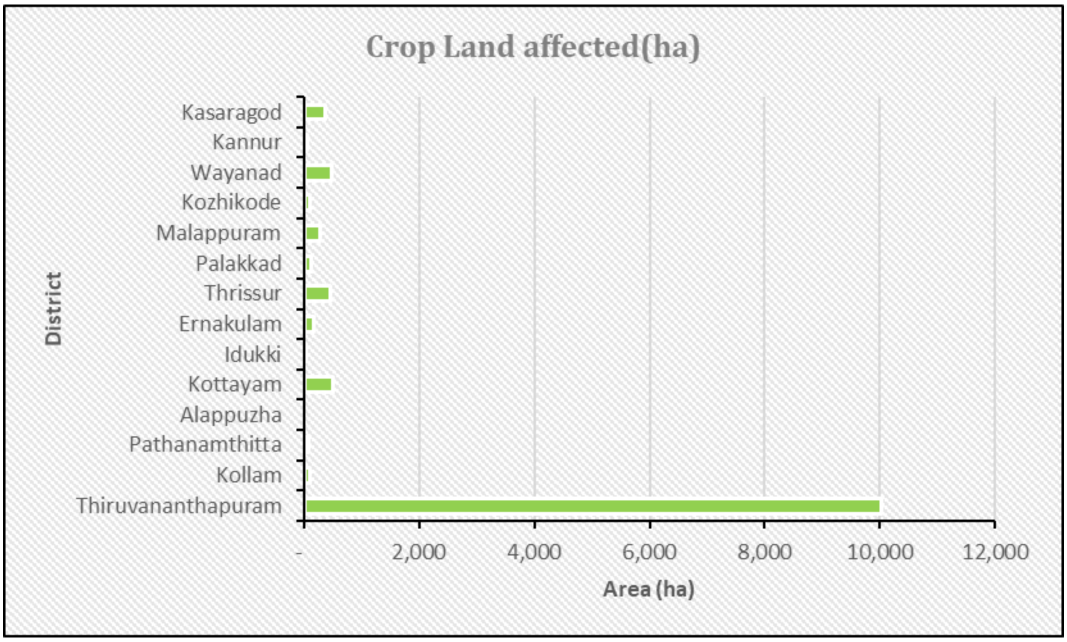


Figure 4-11: Agriculture land affected due to 2014 floods and landslides (April-May)

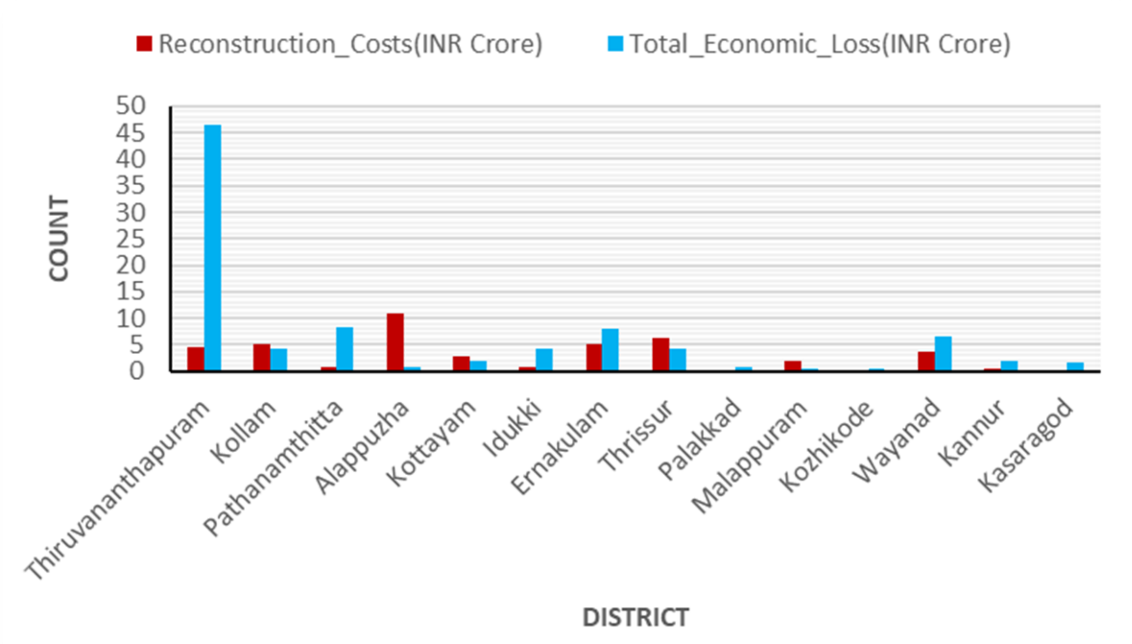


Figure 4-12: Total economic and reconstruction cost for different districts

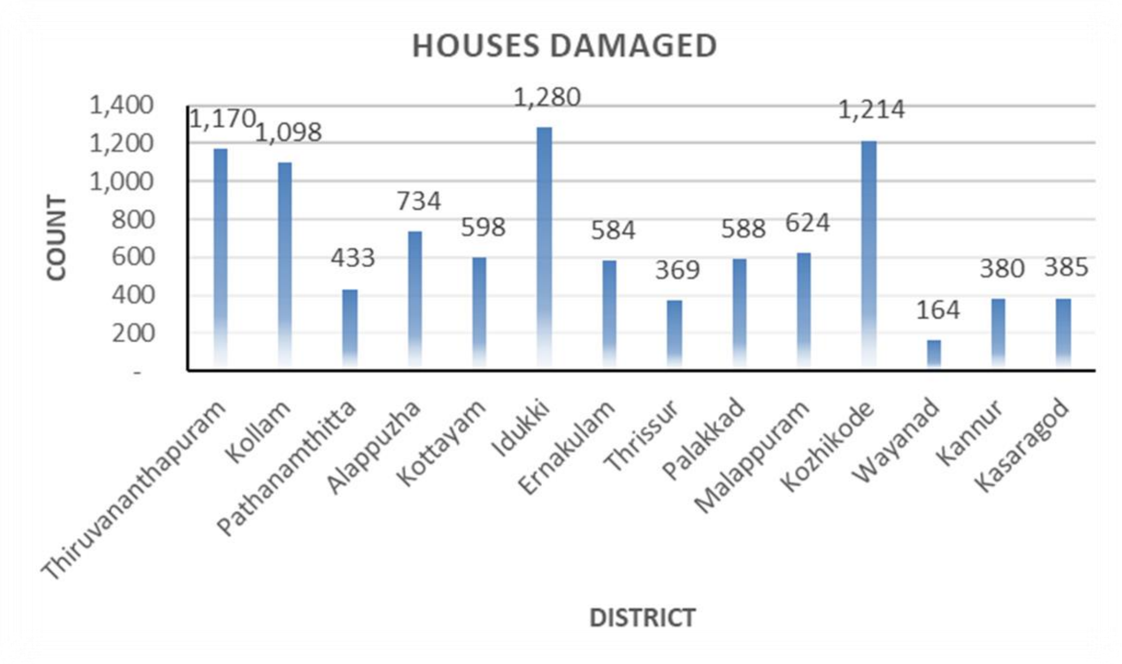


Figure 4-13: District wise number of houses damaged due to 2014 floods and landslides (June-September)

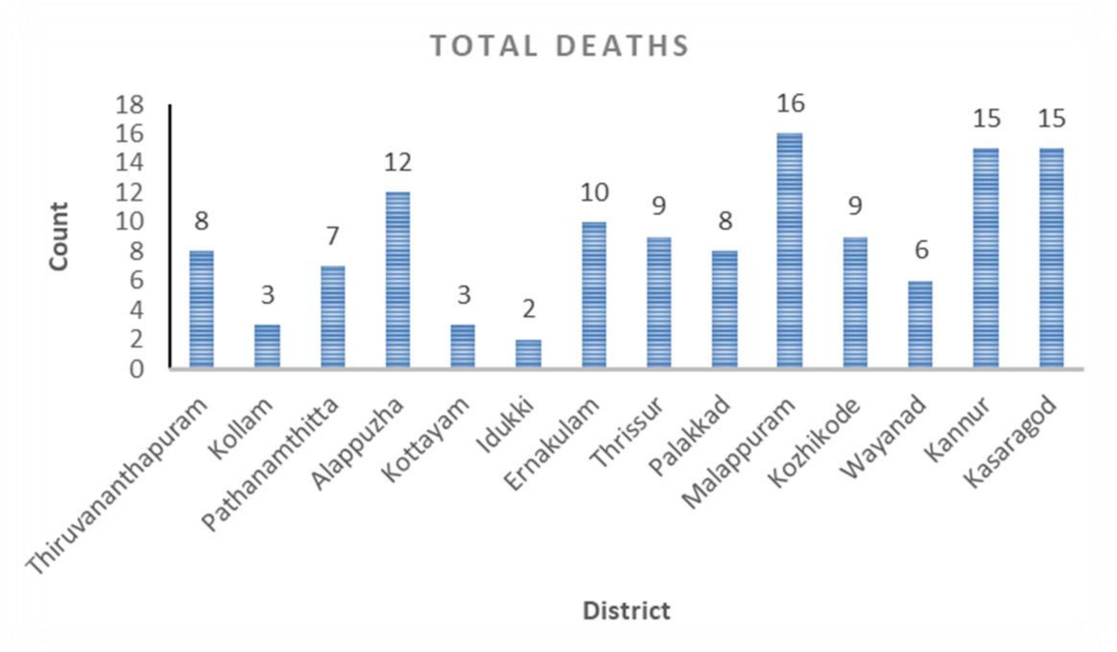


Figure 4-14: District wise fatalities due to 2014 flood and landslides (June-September)

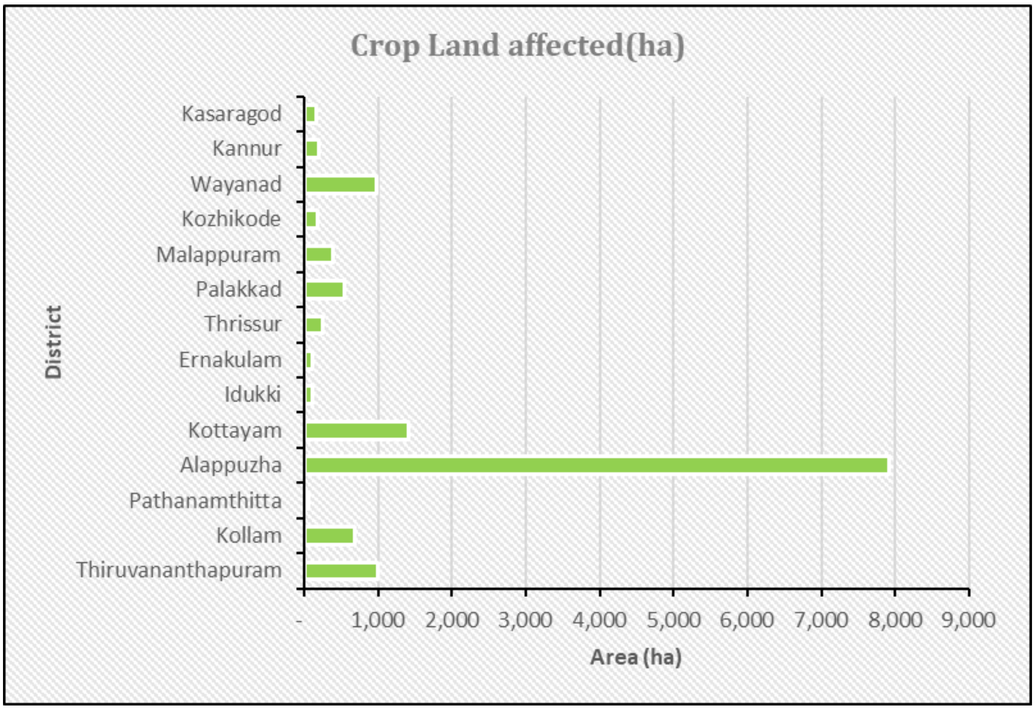


Figure 4-15: Agriculture land affected due to 2014 floods and landslides (August)

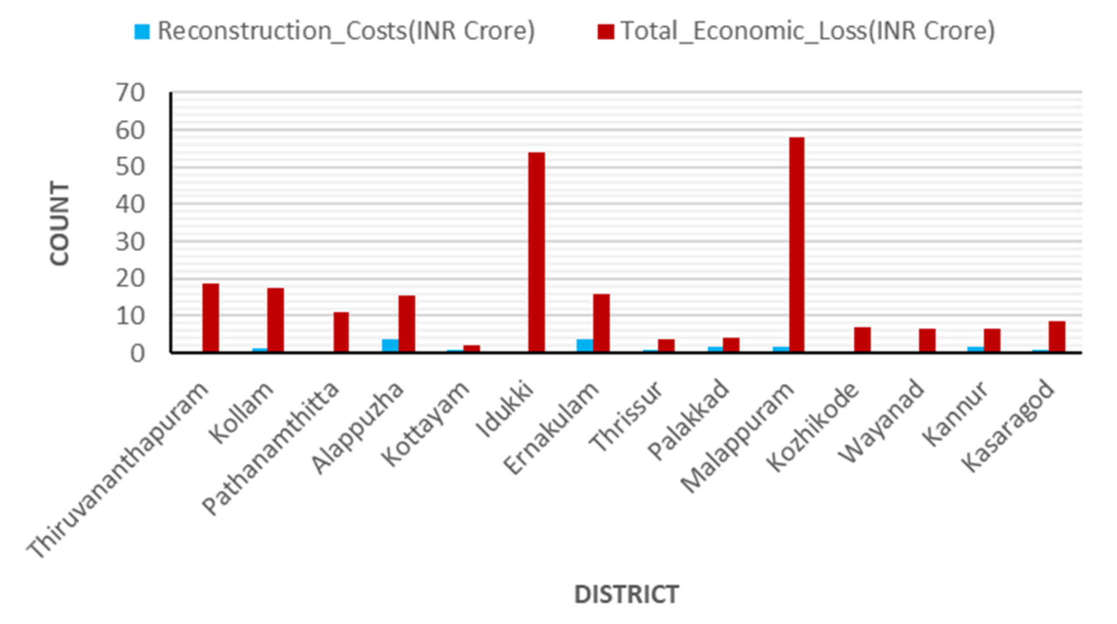


Figure 4-16: Total economic and reconstruction cost for different districts

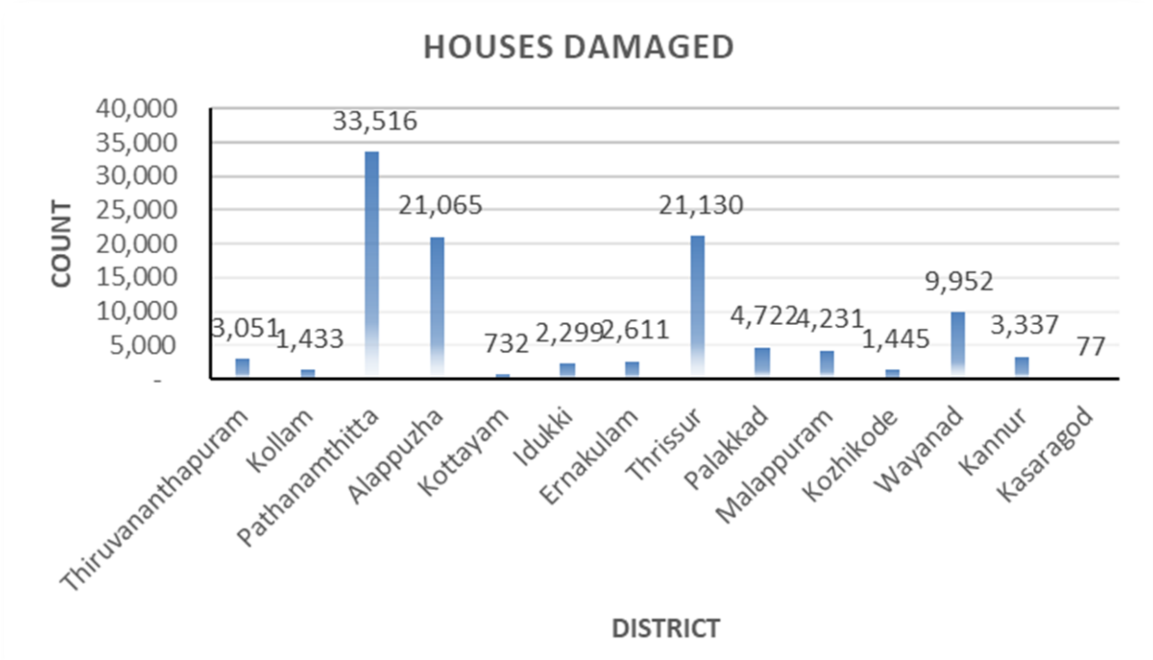


Figure 4-17: District wise number of houses damaged due to 2018 floods and landslides (June-July)

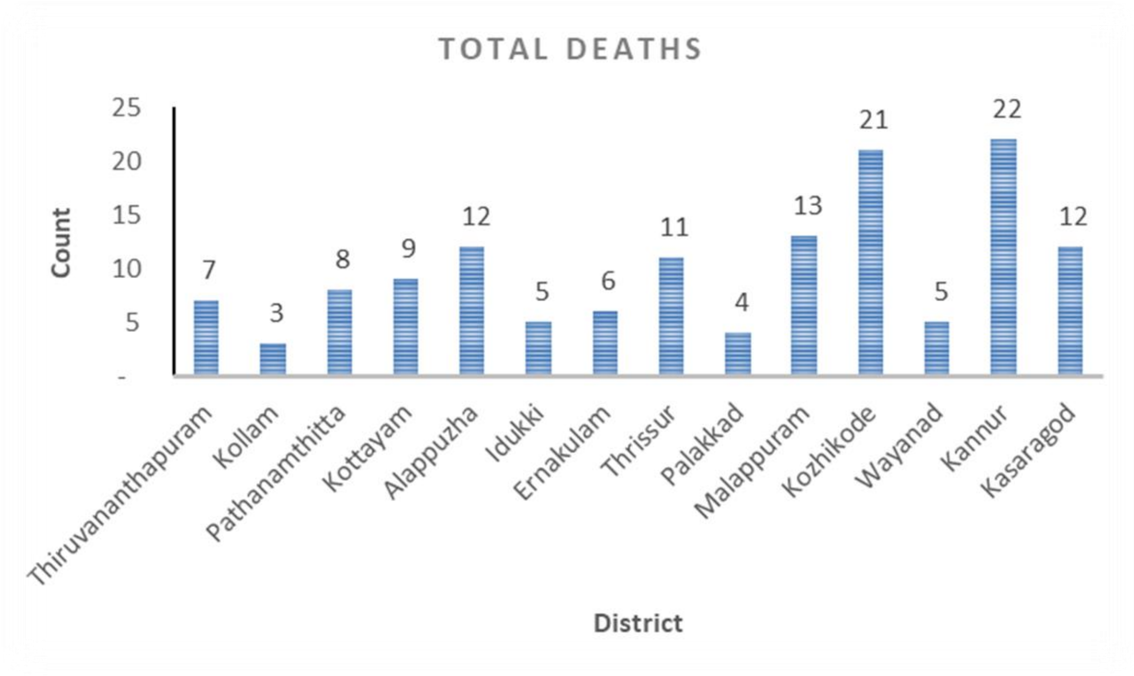


Figure 4-18: District wise fatalities due to 2018 flood and landslides (June-July)

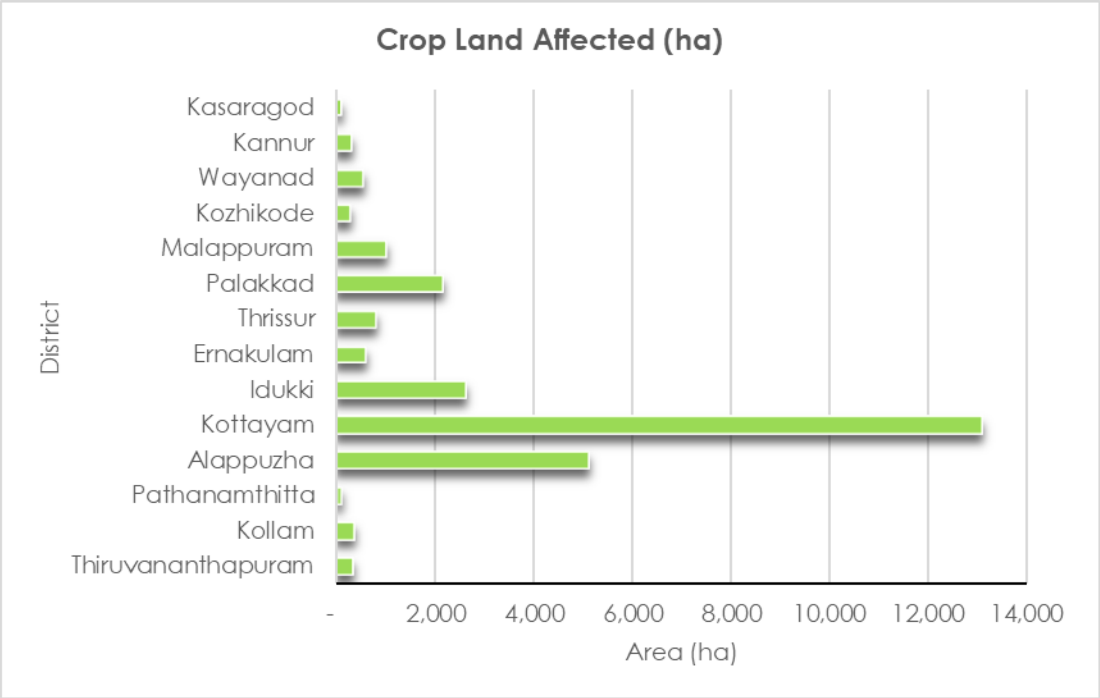


Figure 4-19: Agriculture land affected due to 2018 floods and landslides (June-July)

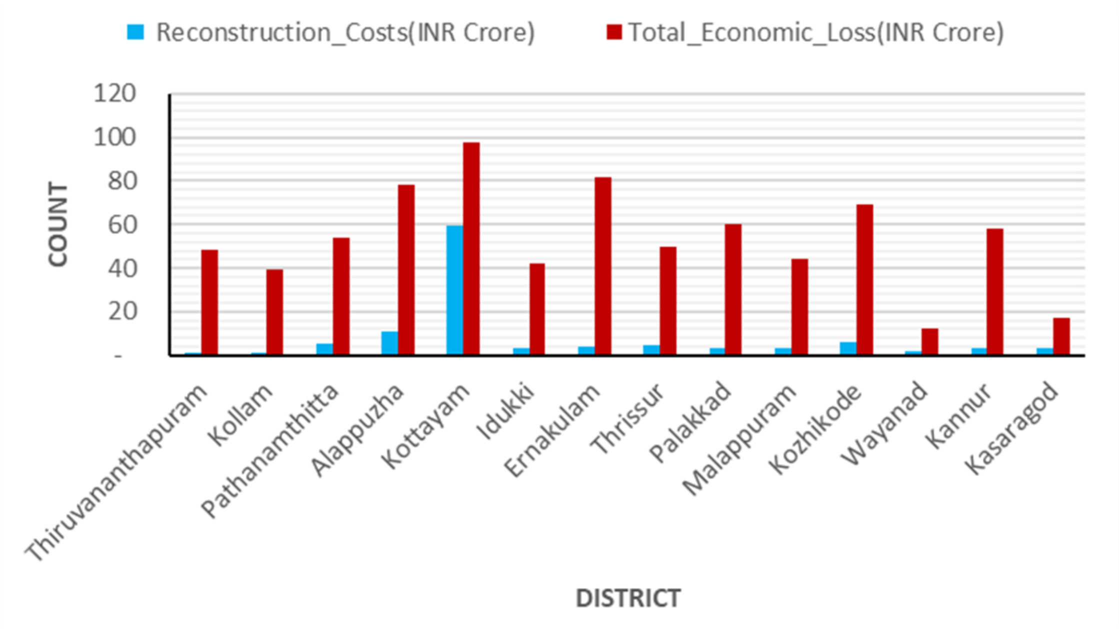


Figure 4-20: Total economic and reconstruction cost for different districts

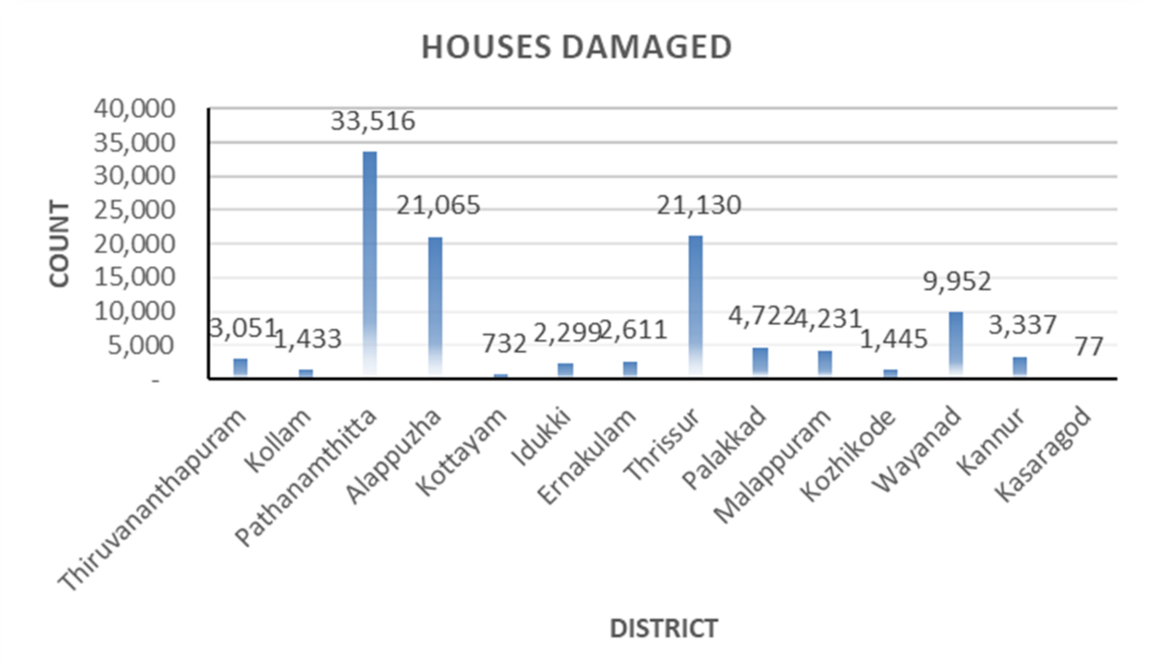


Figure 4-21: District wise number of houses damaged due to 2014 floods and landslides (August)

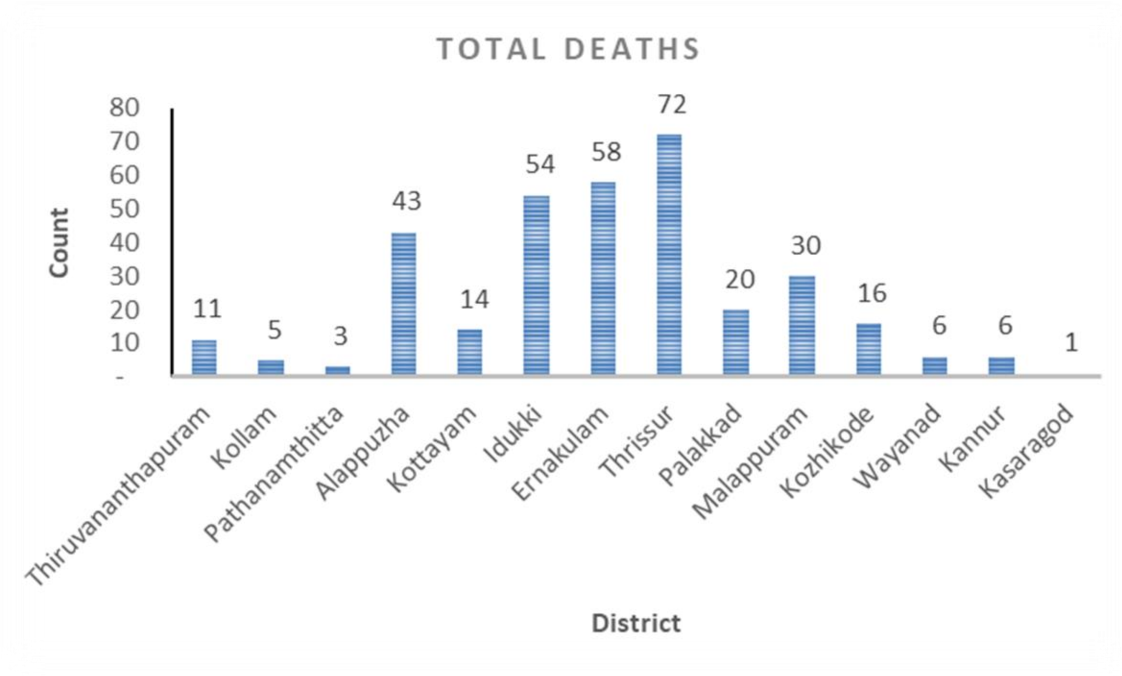


Figure 4-22: District wise fatalities due to 2018 flood and landslides (August)

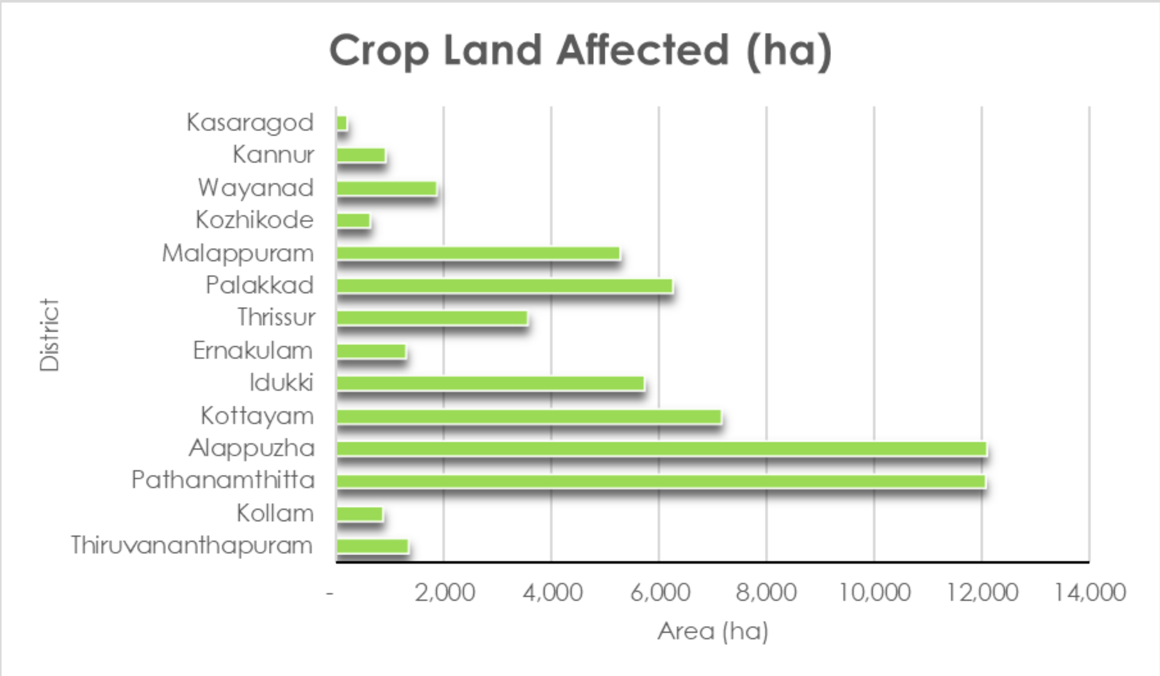


Figure 4-23: Agriculture land affected due to 2018 floods and landslides (August)

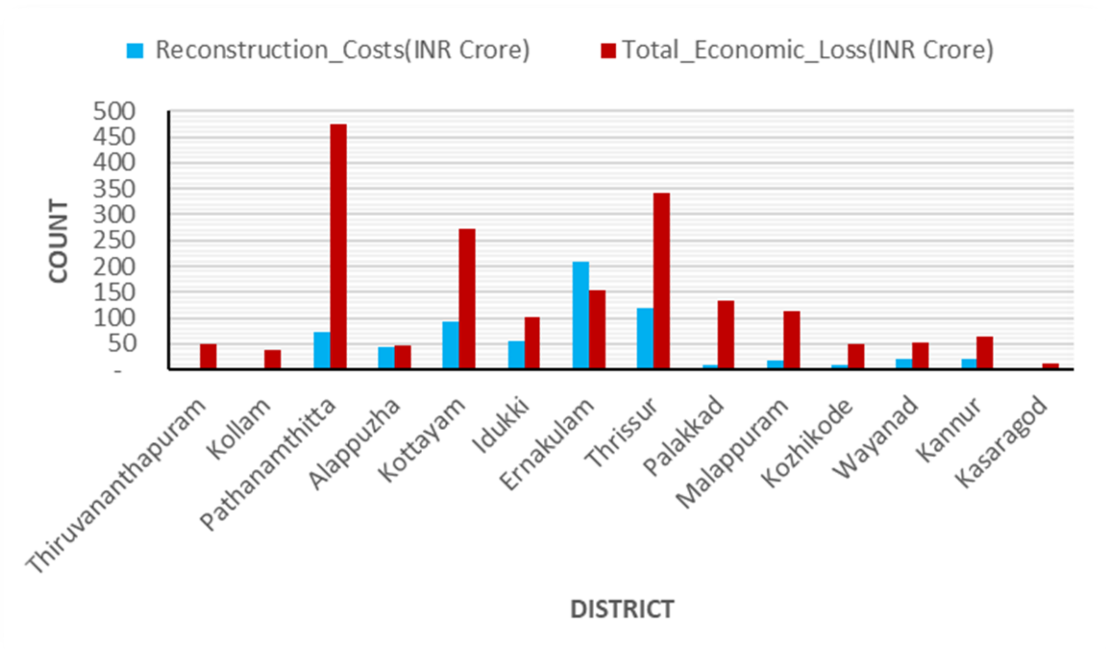


Figure 4-24: Total economic and reconstruction cost for different districts

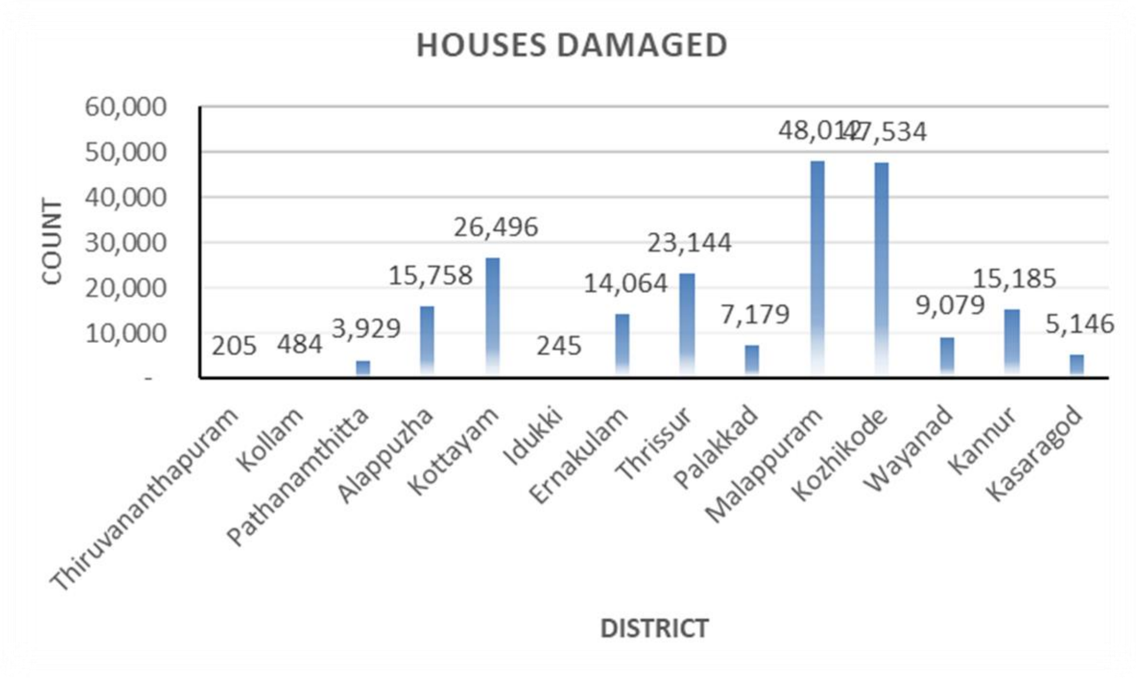


Figure 4-25: District wise number of houses damaged due to 2019 floods and landslides

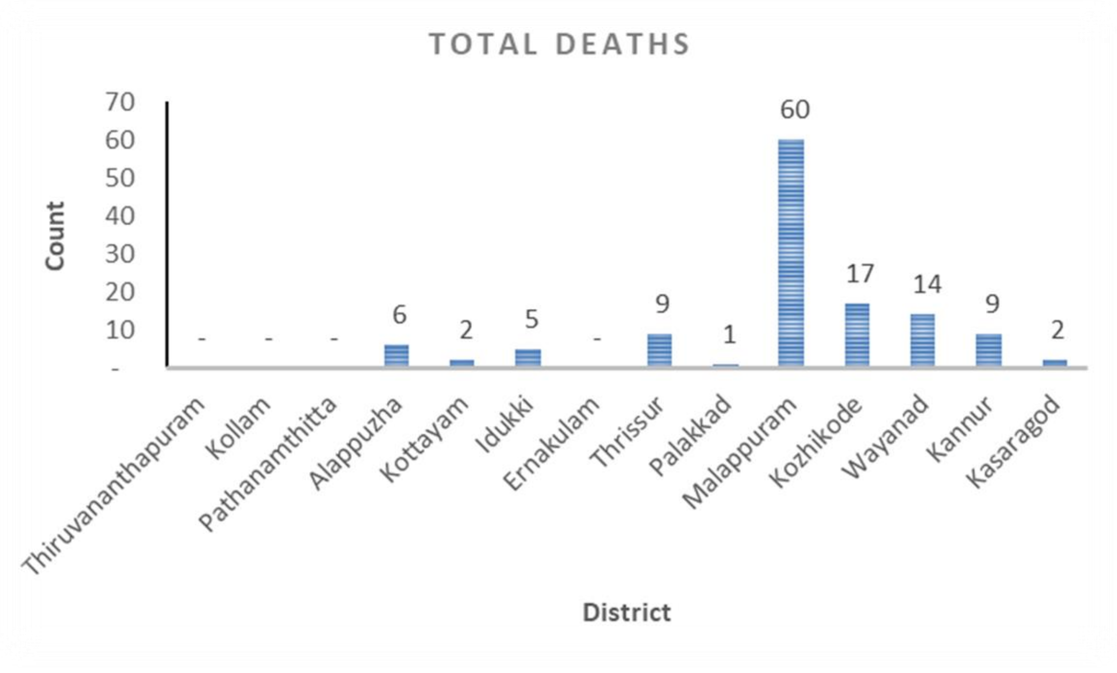


Figure 4-26: District wise fatalities due to 2019 flood and landslides

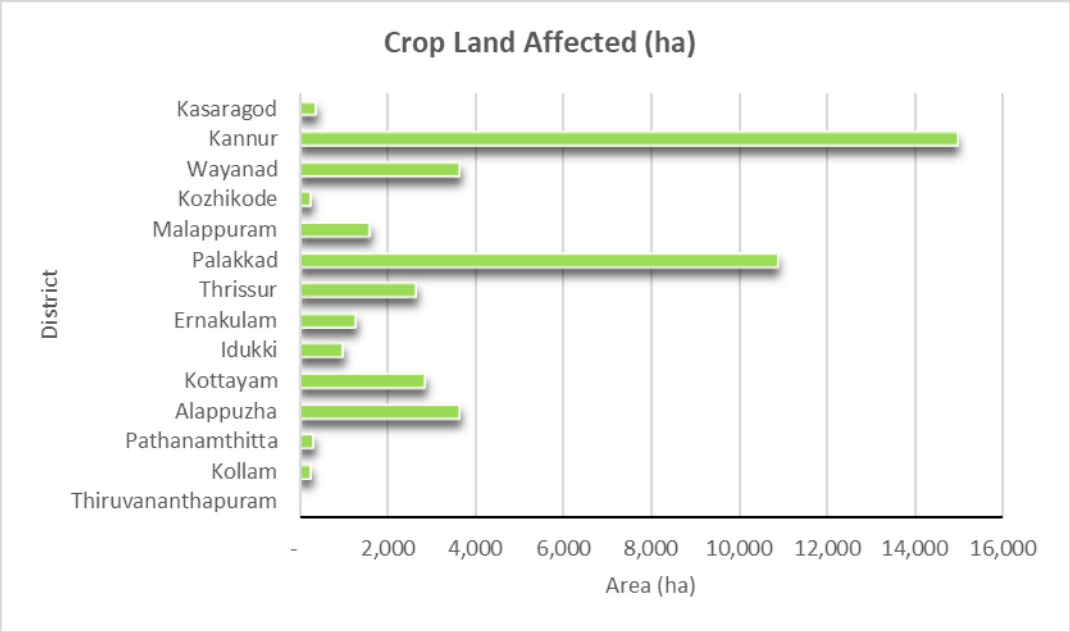


Figure 4-27: Agriculture land affected due to 2019 floods and landslides

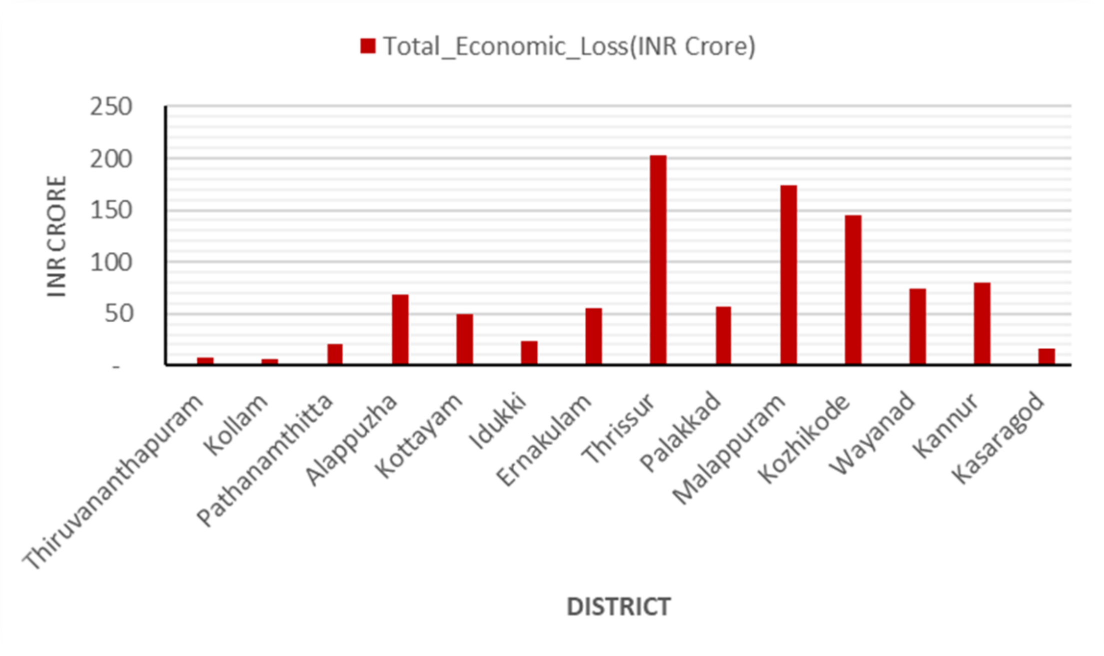


Figure 4-28: Total economic losses for different districts

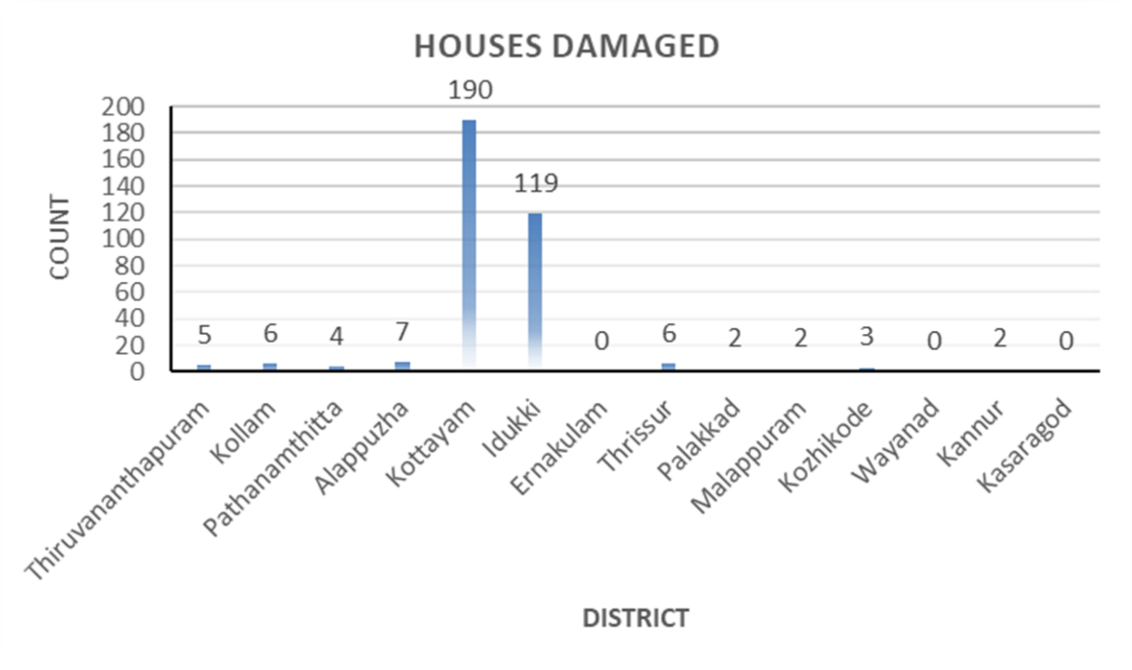


Figure 4-29: District wise number of houses damaged due to 2021 floods and landslides

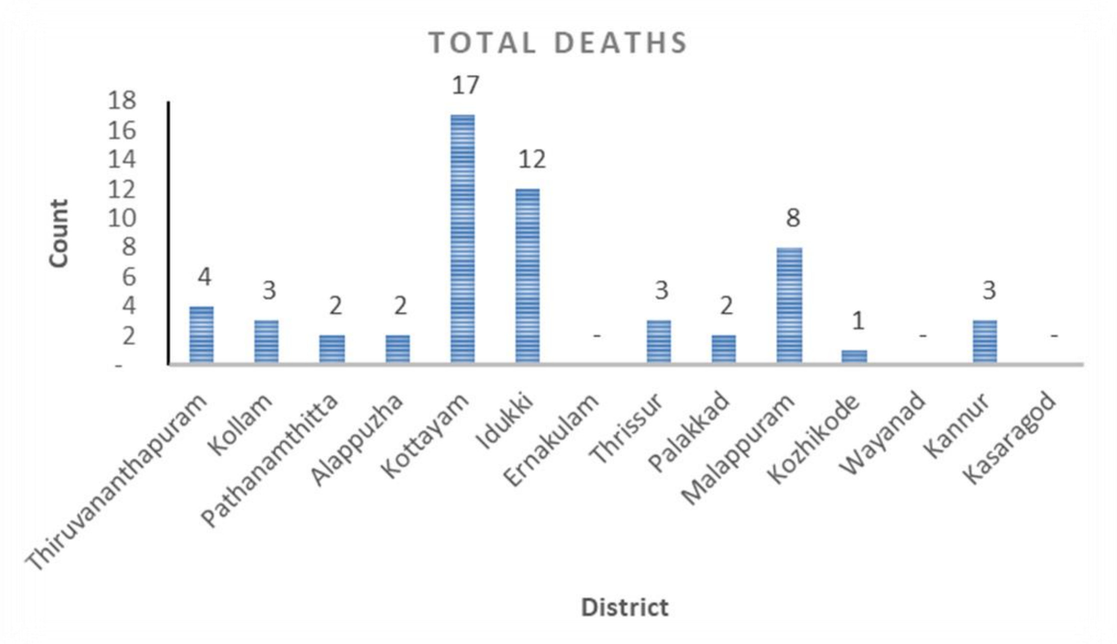


Figure 4-30: District wise fatalities due to 2021 flood and landslides

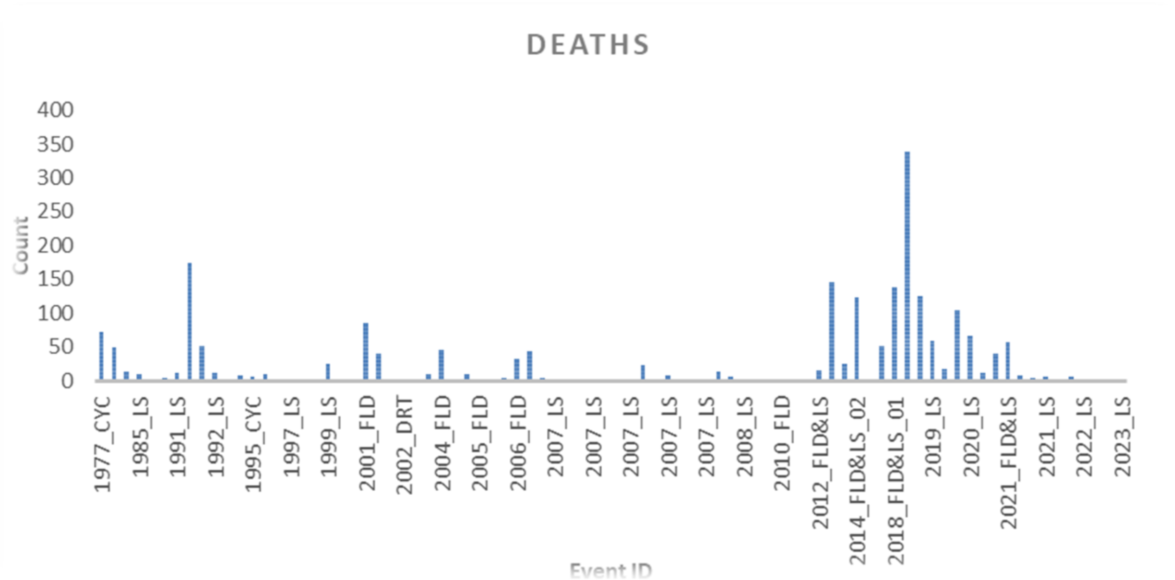


Figure 4-31: Fatalities due to different natural disasters in Kerala state

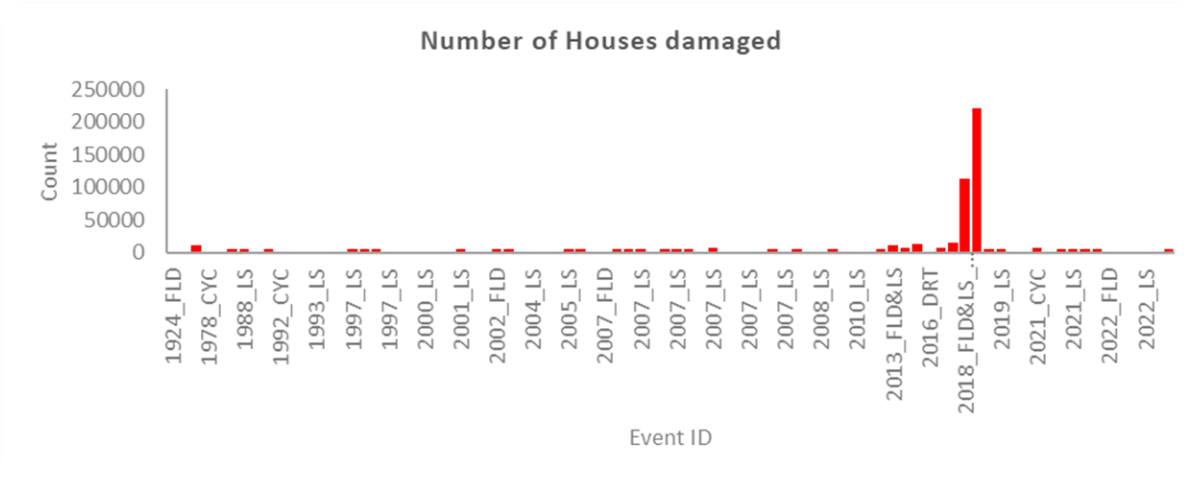


Figure 4-32: Number of Houses damaged due to different natural disasters in the Kerala state

Table 4-2: District wise statistics for flood and landslide events in the state

District	Fatalities	Houses Damaged	Agriculture land affected (ha)	Economic losses (INR Crore)	Reconstruction losses ((INR Crore)
Alappuzha	96	40,831	38,253	230	134
Ernakulam	94	18,471	6,188	318	221
Idukki	87	4,963	10,384	228	61
Kannur	71	20,862	18,155	214	30
Kasaragod	44	6,586	2,211	57	5
Kollam	16	5,093	2,898	107	12
Kottayam	58	29,395	21,948	406	109
Kozhikode	86	53,186	3,731	281	19
Malappuram	141	53,868	9,950	391	24
Palakkad	44	13,292	24,274	255	14
Pathanamthitta	31	39,775	22,028	570	81
Thiruvananthapuram	44	8,314	14,075	482	14
Thrissur	124	45,736	10,504	603	131
Wayanad	31	21,016	10,987	154	26
Grand Total	967	3,61,388	195586	4,296	880

Figure 4-33:Example of compiled major hazard events with damage and loss numbers

Disaster_ID	Disaster_Type	District	Taluk	Start_Year	Total_Deaths	No_Injured	No_People_Affected	Total_Affected	No_Houses_damaged	Agriculture_Land_affected(ha)	Reconstruction_Costs(INR Crore)	Reconstruction_Costs_Adjusted(INR Crore)	Reconstruction_Costs(USD $M)	Reconstruction_Costs_Adjusted(USD $M)	Insured_Damage(INR Crore)	Insured_Damage_Adjusted (INR Crore)	Insured_Damage(USD $M)	Insured_Damage_Adjusted(USD $M)	Total_Economic_Loss(INR Crore)	Total_Economic_Loss_Adjusted (INR Crore)	Total_Economic_Loss(USD $M)	Total_Economic_Loss_Adjusted (USD $M)	Remarks
2024_FLD&LS	Flood and Lands	Wayanad		2024	298																		Source: KSDMA
2023_LS	Landslide	Idukki	Udumbanchola	2023	1				7		0	-	-	-							-	-	www.manorama
2022_LS_01	Landslide	Idukki	Thodupuzha	2022	5						0	-	-	-							-	-	A Pilot Assessme
2022_LS_02	Landslide	Kannur	Iritty	2022	3						0	-	-	-							-	-	timesofindia.ind
2022_LS_03	Landslide	Idukki	Devikulam	2022	1						0	-	-	-							-	-	www.manorama
2022_LS_04	Landslide	Idukki	Peerumade	2022	1						0	-	-	-							-	-	www.manorama
2022_FLD	Flood	7		2022																			
2021_CYC	Storm	Thiruvananthapuram, Kollam, Pa		2021	11	22	7,041	7063	4,419	24,433	0	-	-	-					22.85		3.06	3.39	EM-DAT
2021_LS_01	Landslide	Idukki	peerumade	2021	7				7		0	-	-	-							-	-	
2021_LS_02	Landslide	Kottayam	Kanjirapalli	2021	6				1		0	-	-	-							-	-	
2021_FLD&LS	Flood and Lands	Thiruvananthapuram, Kollam, Pat		2021	57	0	0	0	346	0		-	-	-					300	331.98	40.89	45.25	KSDMA memora
2021_LS_03	Landslide	Kottayam	Kanjirapalli	2021	4				2		0	-	-	-							-	-	
2021_FLD	Flood	Idukki, Kottayam, Pathanamthitta		2021	39		3500	3950			0	-	-	-							-	-	EM-DAT
2020_LS	Landslide	Idukki	Devikulom	2020	66						0	-	-	-							-	-	
2020_FLD	Flood	Idukki, Wayanad, Malappuram, T		2020	104						0	-	-	-					19,000.00	22,042.54	2,532.66	2,938.22	
2019_LS_01	Landslide	Malappuram		2019	59				81	40	0	-	-	-							-	-	
2019_LS_02	Landslide	Wayanad		2019	17				19	40	0	-	-	-							-	-	
2019_FLD&LS	Flood and Lands	Idukki, Wayanad, Malappuram, T		2019	125	0	-	0	2,16,460	43,852	1.135155465	1.39	0.16	0.19					981.87	1,199.29	137.55	168.02	KSDMA memora
2018_FLD&LS	Flood and Lands	Thiruvananthapuram		2018	477	0	39,69,813	-	1,21,703	86,705	788.41	1,045.90	113.08	150.01	-	-	-	-	2,657.62	3,525.61	381.19	505.68	KSDMA memora
2017_CYC	Storm	Thiruvananthapuram, Kollam, Pa		2017	51	234	8,900	9134	3,744	7,817	86.81	120.76	13.47	18.74					431.00		66.89	93.06	EM-DAT
2017_FLD	Flood			2017	80				6705	6000									6.51	9.05	1.01	1.40	Central Water M
2016_DRT	Drought			2016							0	-	-	-							-	-	
2016_FLD	Flood			2016	66				8436	10000									141.07	204.03	21.03	30.42	Central Water M
2015_FLD	Flood			2015	74				6322	4000									49.41	73.32	7.47	11.08	Central Water M
2014_FLD&LS_02	Flood and Lands	Thiruvananthapuram, Kollam, Pat		2014	24	9	-	0	4,249	12,772	19.051993	30.17	3.00	4.74					229.53	363.47	36.08	57.14	KSDMA memora
2014_FLD&LS_01	Flood and Lands	Thiruvananthapuram, Kollam, Pat		2014	123	24	-	0	9,621	14,013	42.26362	66.93	6.64	10.52					89.72	142.07	14.10	22.34	KSDMA memora
2013_FLD&LS	Flood and Lands	Thiruvananthapuram, Kollam, Pat		2013	146	101	-	0	8,320	37,704	23.52152846	38.78	3.85	6.35					20.87	34.41	3.42	5.64	KSDMA memora
2012_FLD&LS	Flood and Lands	Kannur, Kozhikode, Palakkad, Ern		2012	15	6	-	0	689	541	5.73639365	10.54	1.07	1.97					16.30	29.95	3.04	5.59	KSDMA memora
2012_DRT	Drought	Thiruvananthapuram		2012						29,935	1.13699	2.09	0.21	0.39					5,810.66	10,678.65	1,085.50	1,994.89	KSDMA memora
2011_FLD	Flood	1 district		2011	119																		
2010_LS	Landslide	Idukki		2010	3						0	-	-	-							-	-	Paper:Historical
2010_FLD	Flood	2 districts		2010	86																		
2009_LS	Landslide	Wayanad		2009		2			46		0	-	-	-							-	-	Paper:Historical
2009_FLD	Flood			2009	142				22744	26000									607.33	1,448.32	130.33	310.80	Central Water M
2008_LS_01	Landslide	Wayanad		2008	3						0	-	-	-							-	-	Paper:Historical
2008_LS_02	Landslide	Wayanad		2008	3	1					0	-	-	-							-	-	Paper:Historical
2008_FLD	Flood			2008	72				9360	5000									30.79	83.34	6.07	16.44	Central Water M
2007_LS_01	Landslide			2007	22				4500		0	-	-	-							-	-	Paper:Historical
2007_LS_02	Landslide	Kollam, Kottayam, Kannur, Ernaku		2007	13						0	-	-	-							-	-	Paper:Historical
2007_LS_03	Landslide	Thiruvananthapuram		2007	8						0	-	-	-							-	-	Paper:Historical
2007_LS_04	Landslide	Wayanad		2007	5	2			265		0	-	-	-					6.585	19.69	1.67	4.99	Paper:Historical
2007_LS_05	Landslide	Wayanad	Manathavady	2007	4				1		0	-	-	-							-	-	Kouriakose et. al., 2009
2007_LS_06	Landslide	Kozhikode	Koilandy	2007	2				1		0	-	-	-							-	-	Kouriakose et. al., 2009
2007_LS_07	Landslide	Malappuram	Eranadu	2007	2				1		0	-	-	-							-	-	Kouriakose et. al., 2009
2007_LS_08	Landslide	Palakkad		2007	2						0	-	-	-							-	-	Paper:Historical
2007_LS_09	Landslide	Palakkad	Chittur	2007	1				2		0	-	-	-							-	-	Kouriakose et. al., 2009
2007_LS_10	Landslide	Kozhikode	Kozhikode	2007	1						0	-	-	-							-	-	Kouriakose et. al., 2009
2007_LS_11	Landslide	Kozhikode	Kozhikode	2007	1				1		0	-	-	-							-	-	Kouriakose et. al., 2009
2007_LS_12	Landslide	Malappuram	Eranadu	2007	1				1		0	-	-	-							-	-	Kouriakose et. al., 2009
2007_LS_13	Landslide	Palakkad	Alathur	2007	1						0	-	-	-							-	-	Kouriakose et. al., 2009

4.3 Utilization of compiled catalogue

The compiled disaster catalogue, comprising key parameters such as disaster type, location, economic losses, and casualties, serves as a vital tool for various stakeholders involved in disaster risk management and response efforts.

Risk Assessment and Planning: *The catalogue enables policymakers and disaster management agencies to conduct comprehensive risk assessments by analyzing historical data on disaster types, locations, and magnitudes. This information informs the development of risk mitigation strategies, land-use planning, and infrastructure resilience measures to minimize the impact of future disasters.*

Emergency Response and Preparedness*: During disaster response operations, the catalogue provides valuable insights into the affected areas, population demographics, and infrastructure vulnerabilities. Emergency responders use this information to prioritize resource allocation, deploy personnel and equipment, and coordinate rescue and relief efforts effectively.*

Research and Analysis*: Researchers and academics utilize the catalogue to conduct empirical studies, analyze trends, and evaluate the effectiveness of disaster management strategies. By examining historical data on economic losses, casualties, and environmental impacts, they contribute valuable insights to the field of disaster risk science and inform evidence-based decision-making.*

In summary, the utilization of the compiled disaster catalogue - based on key parameters - is essential for informed decision-making, effective emergency response, and long-term resilience building. By leveraging this valuable resource, stakeholders can mitigate the impacts of disasters, save lives, and promote sustainable development in disaster-prone regions.

4.4 Maps of Historical flood and landslide events economic losses

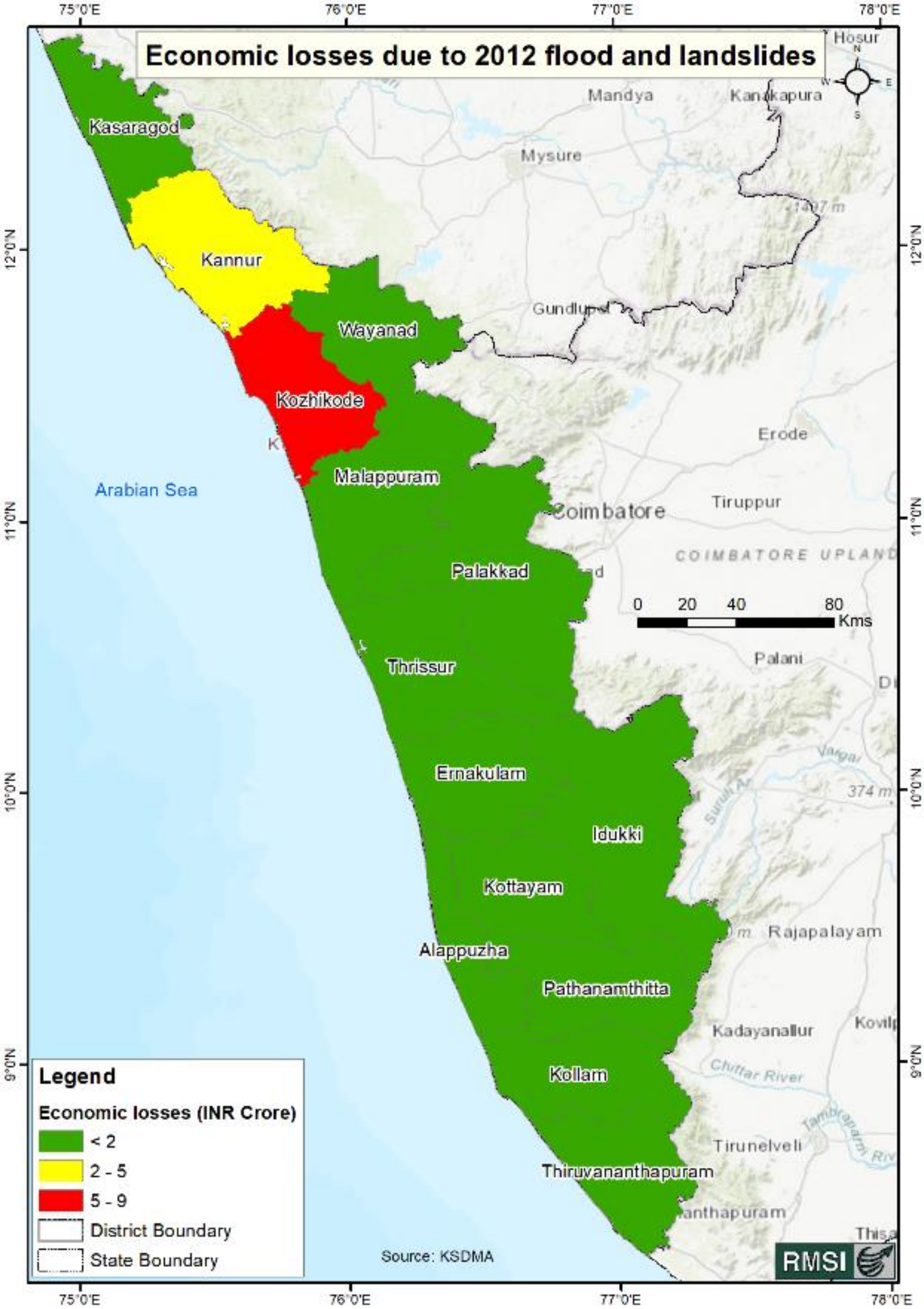


Figure 4-34: District wise 2012 flood and landslide economic losses of Kerala

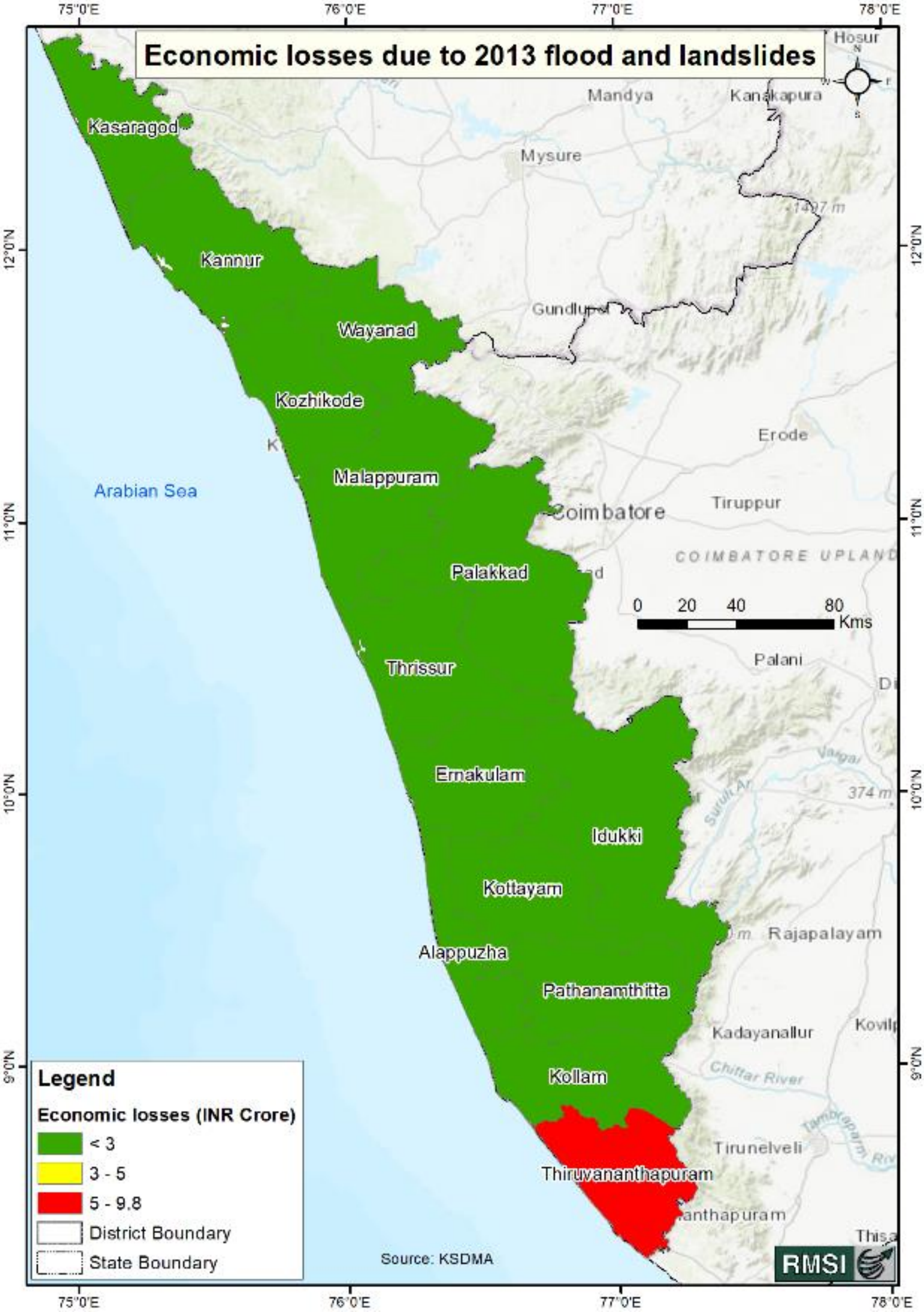


Figure 4-35: District wise 2013 flood and landslide economic losses of Kerala

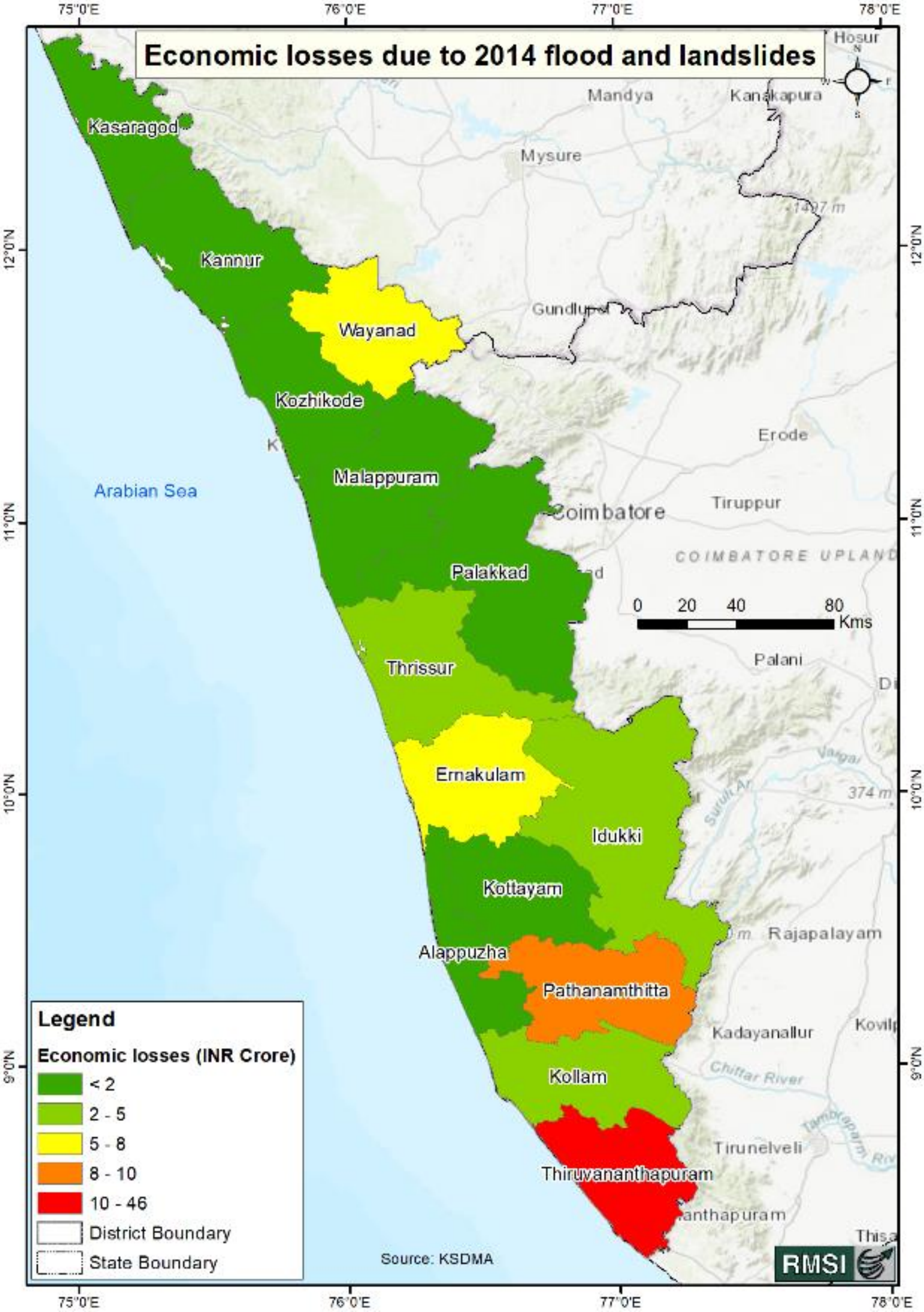


Figure 4-36: District wise 2014 (April-May) flood and landslide economic losses of Kerala

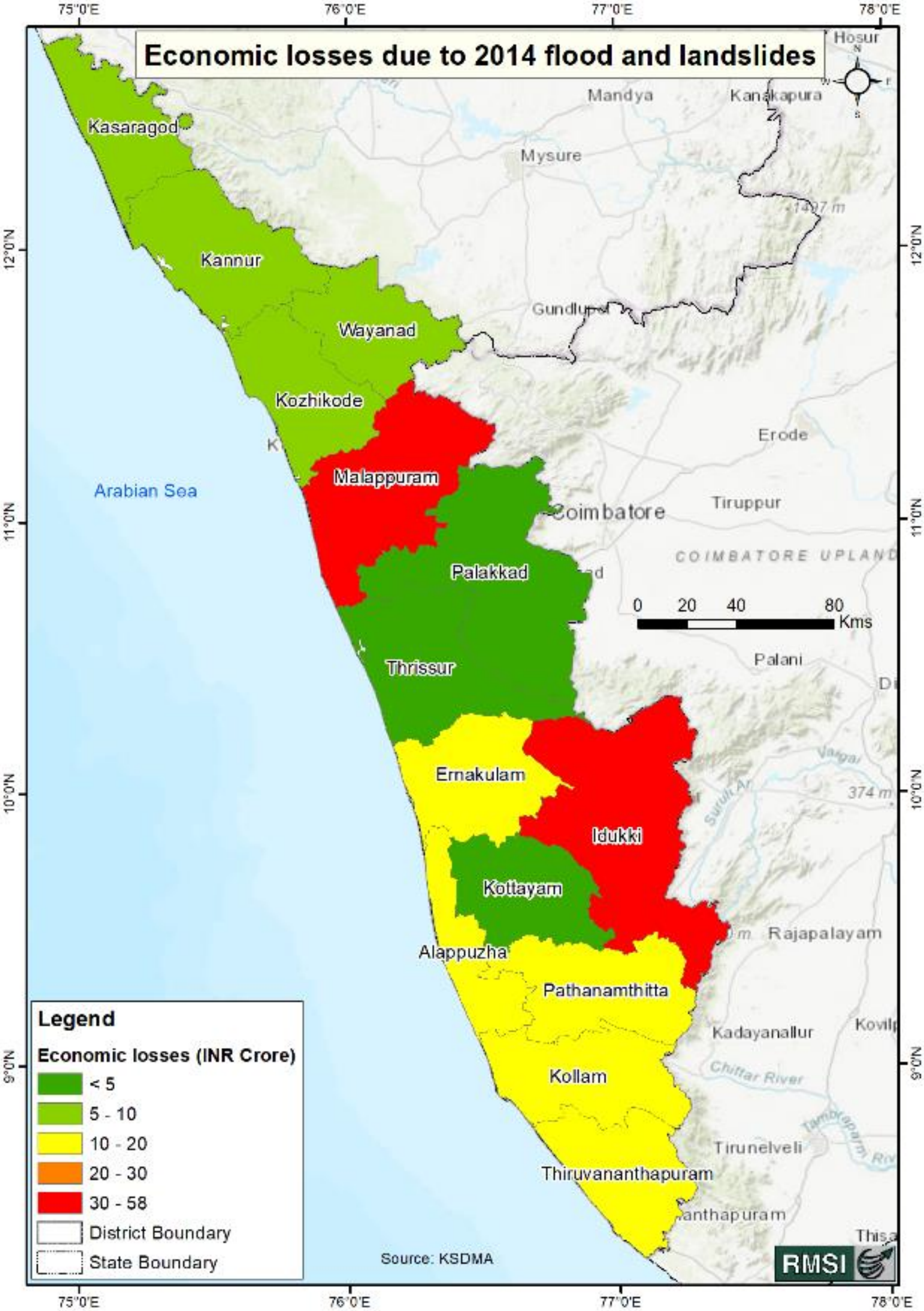


Figure 4-37: District wise 2014 (June -Sep) flood and landslide economic losses of Kerala

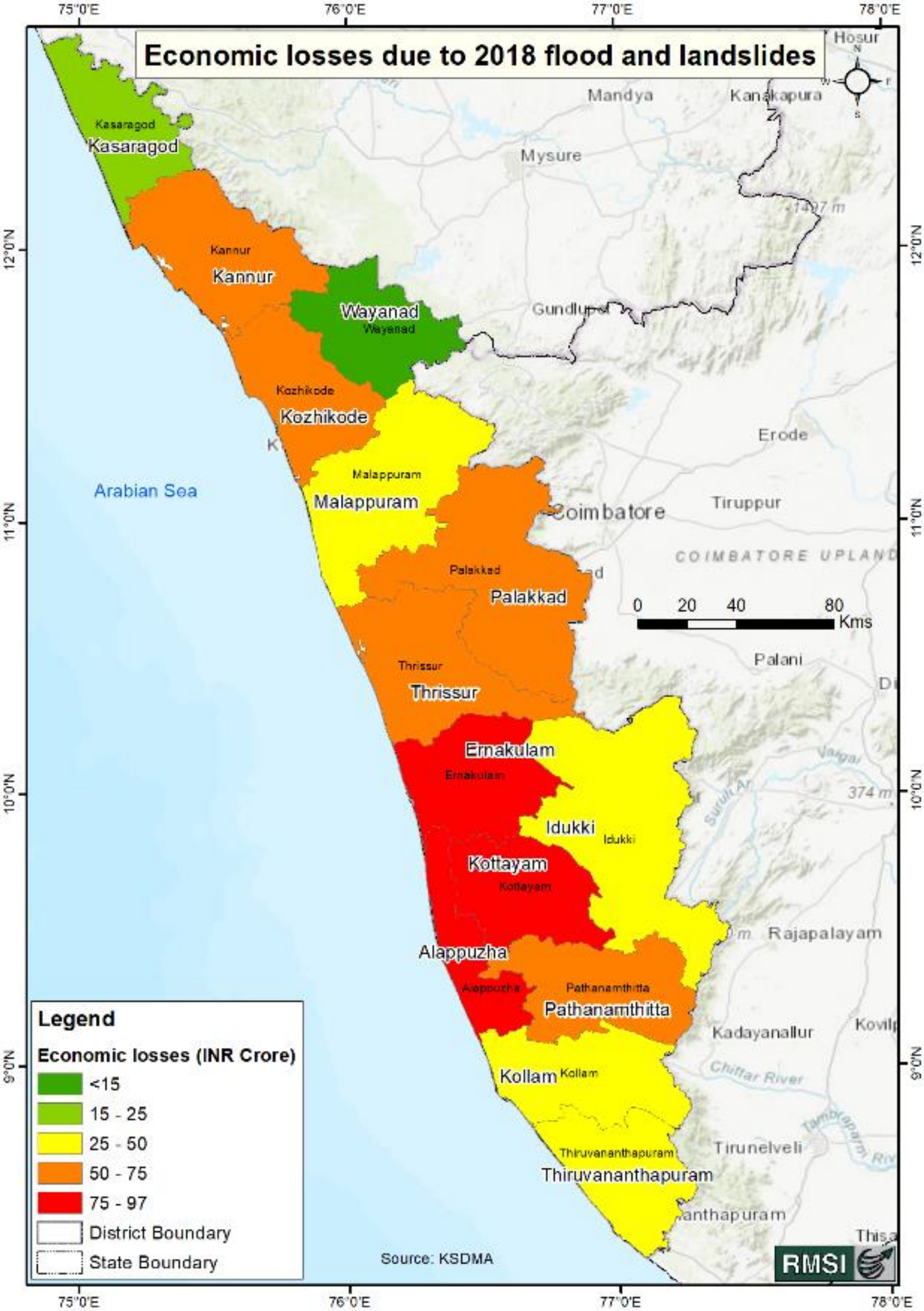


Figure 4-38: District wise 2018 (June-July) flood and landslide economic losses of Kerala

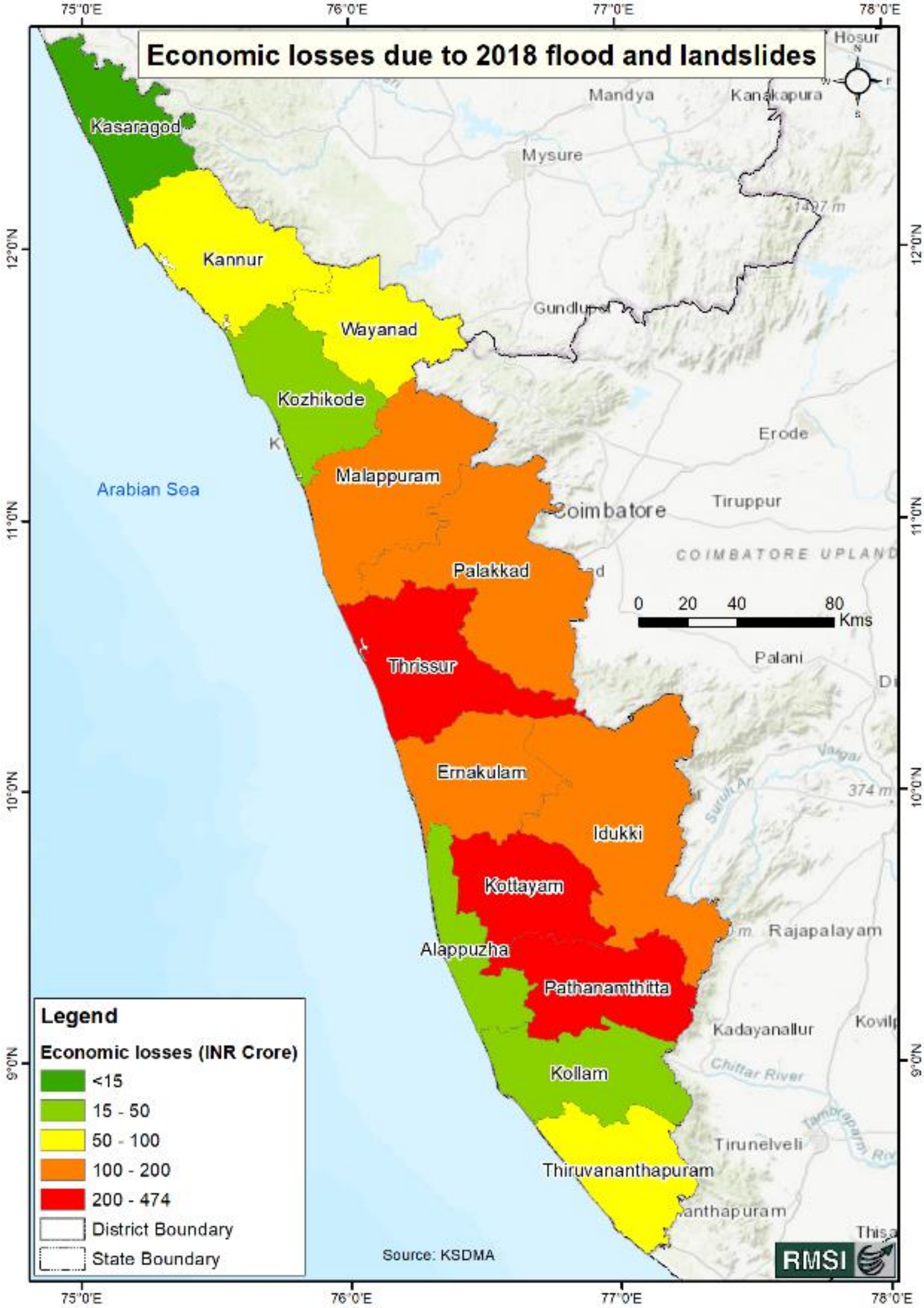


Figure 4-39: District wise 2018 (August) flood and landslide economic losses of Kerala

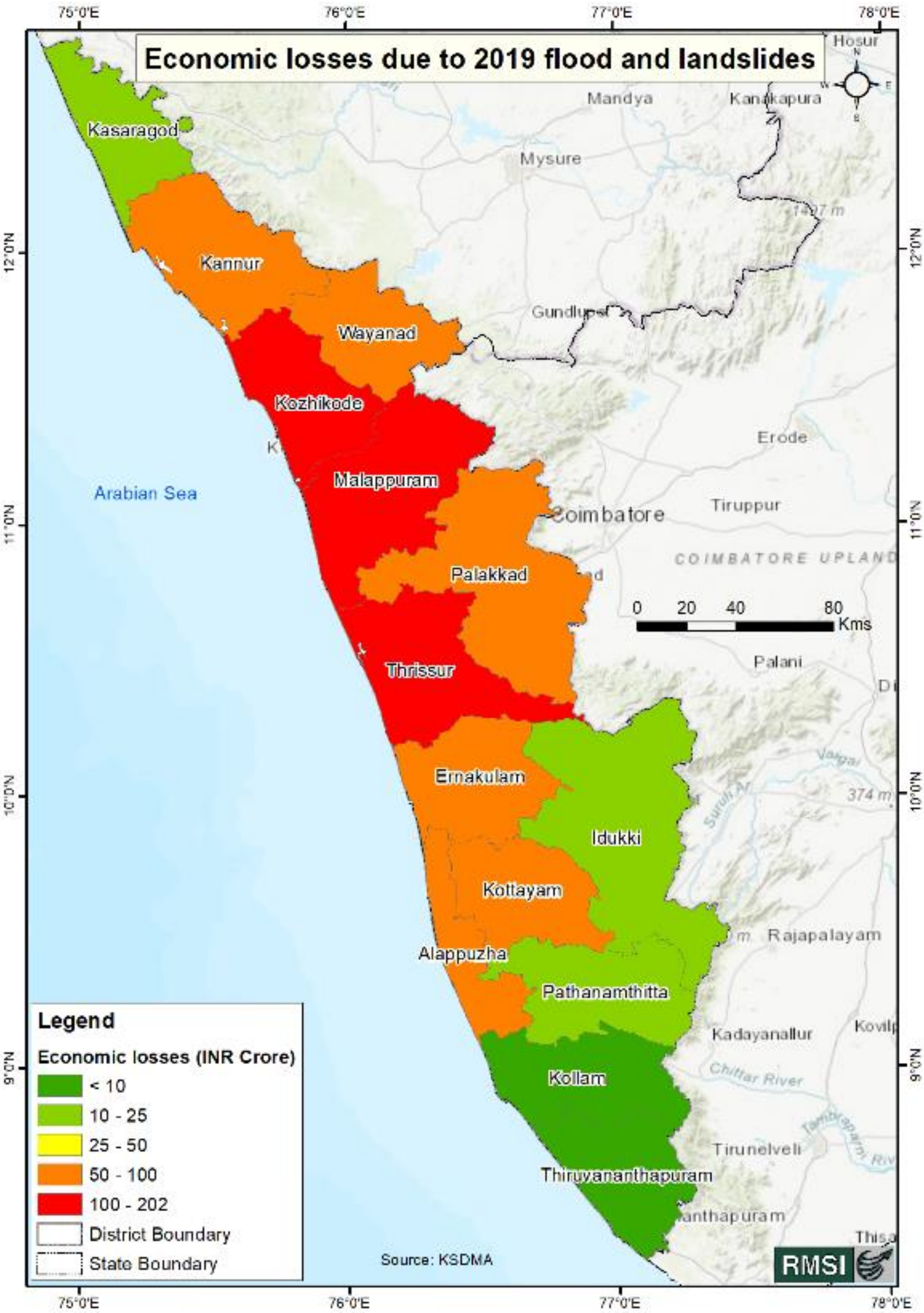


Figure 4-40: District wise 2019 flood and landslide losses of Kerala

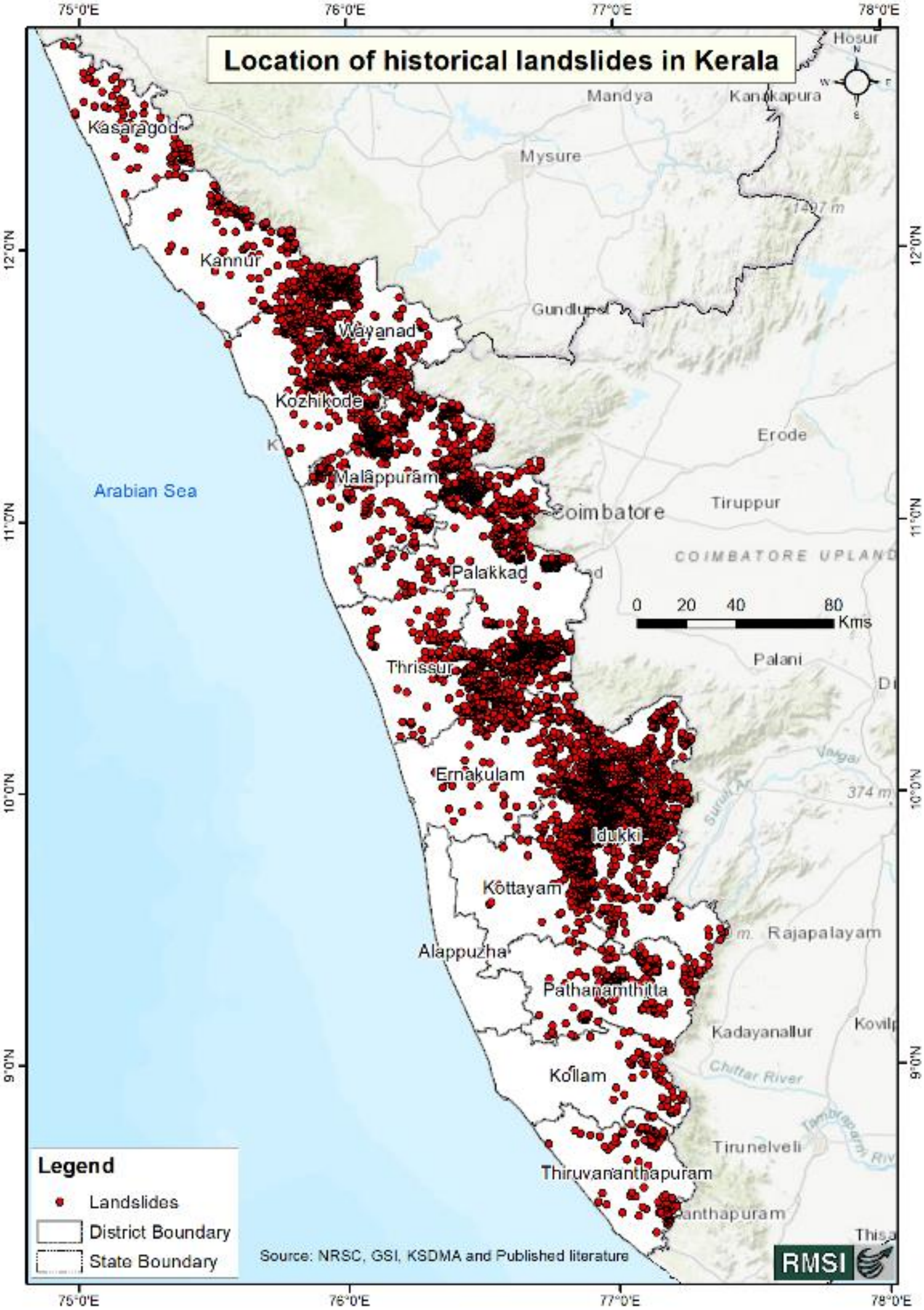


Figure 4-41: Spatial distribution of historical landslides in Kerala (last 30 years)

5

Preparation of Disaster Risk Assessment Report

5 Preparation of Disaster Risk Assessment Report

5.1 Technical Report Describing Data Collection and Limitations

This section details the process of data collection, key datasets utilized for the study, and the identified data gaps and limitations. It highlights efforts to address these gaps to ensure the data is reliable and suitable for hazard and risk assessment in Kerala.

5.1.1 Administrative Boundaries

Administrative boundary data were sourced from KSDMA and included boundaries at various levels such as districts, talukas, villages, and LSGs. However, the following gaps and issues were identified:

***Topological Corrections:** The RMSI team conducted extensive analysis to correct topological errors, ensuring data consistency and accuracy.*

Missing LSG Data in Palakkad District:

One specific gap was identified in the Local Self Government (LSG) boundaries within Palakkad district. Specifically, the Sholayoor, Pudur, and Agali LSGs in the Attappati Taluka were missing updated Taluka codes. The RMSI team addressed this issue by identifying the errors and filling them with the latest Taluka code, T09007, ensuring that the administrative boundary data is accurate and up-to-date.

Through these efforts, the administrative boundary data was standardized, updated, and made suitable for use in hazard and risk modeling.

5.1.2 Building Footprint Data

Partial building footprint data for five districts—Ernakulam, Kollam, Kannur, Thiruvananthapuram, and Kozhikode—was provided by KSREC. However, the data contained significant gaps, building footprints were missing for other districts, limiting the statewide analysis. Essential attributes such as construction type, number of floors, and construction costs were absent.

To overcome this limitation, the RMSI team enriched the dataset by adding the building footprint dataset to include the missing attributes. This effort was extended to cover the entire state of Kerala, ensuring comprehensive and consistent building footprint data for hazard assessment.

5.1.3 Bridges and Flyovers

The data received from KSREC for bridges and flyovers consisted only of point locations, without any associated attribute information. To address this, the RMSI team mapped these as line features representing bridges and flyovers, and added the appropriate attribute information to provide a comprehensive representation of these structures. Despite multiple requests to the PWD Kerala through RKI for additional data, no further information was shared.

5.1.4 Population and Household Data

Population and household data were primarily derived from the Census 2011 dataset, supplemented by projections to 2023. Identified gaps included:

Some villages were recorded with zero population, an anomaly that could skew risk assessments. RMSI team filled these gaps using its in-house census population data to provide realistic estimates. Further, Attappadi (HQ: Agali) is a tribal Taluka in Kerala state covering an area of 735 km^2 (284 sq mi). It was carved out of Mannarkkad Taluka in Palakkad district in February 2021. We distributed their projected population to 2023 using weighted built-up area.

Projections from 2011 to 2023 involved inherent uncertainties, particularly in areas experiencing significant demographic *changes. These adjustments ensured that population data is up-to-date and capable of supporting socio-economic impact assessments for hazard scenarios.*

5.1.5 Historical Hazard Events Data

The compilation of historical hazard event data faced several limitations:

The compilation of historical hazard event information from sources such as KSDMA, GSI, NRSC, EM-DAT, IMD, CWC and literature revealed significant gaps. For floods, spatial geometry and event duration were frequently missing, making it difficult to accurately map and analyze the extent and impact of these events. In the case of landslides, inventory data with latitude and longitude was available from NRSC, GSI, and literature sources. However, the absence of occurrence dates for a majority of events posed challenges in correlating these events with triggering factors such as rainfall or earthquakes.

***Economic Loss Data:** A critical limitation in the historical hazard event data was the lack of separate economic loss values for floods and landslides. Most data sources reported combined losses for flood and landslide, preventing a granular assessment of the economic impact of individual hazard types. This limitation significantly hindered the validation of our models, as hazard-specific loss data is crucial for ensuring accuracy in risk assessment and economic loss modeling.*

The primary data gaps and limitations identified across various datasets are summarized as follows.

Table 5-1: Data gaps and filling approaches for different datasets

Dataset	Data Source	Gaps and Limitations	Approach to Address Gaps
Administrative Boundaries	KSDMA	Missing LSG boundary data in Palakkad district (Sholayoor, Pudur, and Agali in Attappati Taluka).	Updated missing Taluka codes using latest data (T09007).
Building Footprints	KSREC	Partial coverage for five districts and missing key attributes (construction type, floors, costs).	Enriched attributes and extended coverage to the entire state.
Bridges/Flyovers	KSREC/KSDMA	Data received as point locations without attributes.	Mapped as line features and added attributes; no additional data was shared despite multiple requests to PWD.
Population Data	Census 2011/RMSI	Zero population in some villages; challenges in projecting population to 2023.	Gaps filled using in-house data and realistic estimates.
Historical Hazard Events	KSDMA, NRSC, GSI	Missing spatial and temporal data for flood and landslide events; combined economic loss data for hazards.	Highlighted limitations and incorporated available data into analysis with caution.

5.1.6 Recommendations

Based on the data gaps and limitations the following recommendations are important to improve the quality and availability of data for future updates on hazard and risk assessments:

1. *General: Further, detailed attribute information should be updated in gaps, wherever needed in the current Databases Periodic updation of disaster datasets (preferably yearly or after a major disaster event) as well as yearly updation of exposure database should be carried out as Kerala State is going through rapid development.*
2. *Updation of Building Footprint Database: The housing building footprint database for 5 districts (Ernakulam, Kollam, Kozhikode, Thiruvananthapuram and Kannur) was incomplete and RMSI not only filled this gap but also for rest of State from its in-house database. Building footprint database should be regularly updated at-least once a year as State is witnessing rapid development.*
3. *Updation of Bridges/Flyover Database: The current geospatial database developed by RMSI does not contain name of bridges/ flyover, year of construction, year of major repair etc., and should be updated on priority along with road transport network of the State and then regularly twice a year before (by April) and after end of heavy rains (December).*
4. *Centralized Disaster Database at Event Level: Establish a unified database with detailed spatial, temporal, and disaggregated economic socio-economic loss data at disaster event level (in additional to annual aggregate database) for floods, landslides, cyclones, storm surges, drought and other hazards impacting different parts of Kerala State.*
5. *Regular Updates for Administrative Boundary Data: Ensure at-least once a year updates and validations of Local Self Government (LSG), Towns, Cities, Taluka, Municipality and Municipal Corporations, District and State boundaries, in collaboration with local authorities, KSREC and Survey of India.*
6. *Strengthen Inter-Agency Collaboration: Build a centralized data-sharing platform and foster regular coordination among agencies like KSDMA, KSREC, NRSC, GSI and PWD for data improvements.*

6 Kerala State Vulnerability

6.1 Introduction

Analyzing Kerala State's vulnerability involves a multifaceted examination of its exposure, sensitivity, and adaptive capacity to various natural hazards. With its diverse geography, dense population, and significant socio-economic activities, Kerala faces considerable risks from hazards such as floods, landslides, cyclonic winds, storm surges, and droughts. Vulnerability analysis entails assessing the spatial distribution of vulnerable populations, infrastructure, and ecosystems, identifying hotspots of risk, and understanding the underlying drivers of vulnerability, including socio-economic disparities, urbanization trends, environmental degradation, and climate change impacts. By comprehensively evaluating these factors, policymakers and stakeholders can develop targeted interventions and resilience-building strategies to reduce vulnerability, enhance adaptive capacity, and promote sustainable development in Kerala State.

In this section, RMSI is currently analyzing available risk index maps prepared by KSDMA, but detailed risk assessment analysis will be carried out based on NatCAT analysis, which is under the scope of the Component 2 report.

6.2 Hazard Vulnerability Analysis

The preparation of the Multi-Hazard Vulnerability Map of Kerala involved a comprehensive methodology encompassing data collection, hazard analysis, risk assessment, and map visualization. Initially, data on various hazards (floods, landslides, coastal erosion, and cyclones) were gathered from sources such as CWC, GSI, and IMD. Socio-economic data, population density, and infrastructure information were integrated to assess exposure and vulnerability. Each hazard was analyzed separately using GIS tools to create intensity maps. These maps were then overlaid with exposure and vulnerability data to develop composite risk maps. A multi-hazard risk index was calculated by assigning weights to different hazards based on their impact and frequency. Finally, GIS software was used to produce a detailed, color-coded map indicating low, moderate, and high-risk areas, validated through field surveys and expert reviews.

The Multi-Hazard Vulnerability Map of Kerala visually represents the varying levels of risk across the state, aiding in disaster management and mitigation planning (Figure 6-1). Green areas on the map indicate low-risk zones with minimal exposure and vulnerability to hazards, while yellow areas represent moderate risk with some exposure and vulnerability. Red areas denote high-risk zones that are highly exposed and vulnerable to multiple hazards such as floods, landslides, coastal erosion, and cyclones. For instance, coastal districts like Kasaragod and Kannur show significant high-risk zones due to coastal erosion and cyclones, whereas hilly regions like Wayanad and Idukki are marked high-risk for landslides. This map serves as a tool for local authorities and policymakers to prioritize resource allocation, enhance community preparedness, and implement effective mitigation strategies.

6.3 Socioeconomic Vulnerability Analysis

The socioeconomic vulnerability assessment for the state of Kerala focuses on identifying the location and degree of residents' vulnerability to various hazards. This comprehensive methodology involves several steps, integrating multiple demographic and socioeconomic parameters to provide a detailed *understanding of vulnerability across the state. As per KSDMA methodology provided in Trivandrum HVRA report, key parameters influencing socioeconomic vulnerability are identified. These parameters include the literacy rate, total population, total working population, sex ratio, 0-6 age group population, number of households, households without electricity connection, households with no drainage or open drainage, unhygienic drinking water sources, house roof materials, house wall materials, and the number of slums per ward. Each parameter is selected based on its significance in contributing to the overall vulnerability of the population. Next, data for each parameter is collected from reliable sources such as the 2011 Census of India, National Sample Survey Organization (NSSO) reports, KSDMA reports, and other governmental and non-governmental organizations. Ensuring that the data is current and accurate is crucial for a valid assessment.*

The collected data is then normalized to ensure comparability across different scales and units. This process typically involves converting raw data into a standard format using techniques such as min-max normalization or z-score normalization. Normalization helps in creating a uniform scale for all parameters and facilitating accurate comparisons. Following normalization, weights are assigned to each parameter based on their relative importance in influencing vulnerability. These weights are determined through expert consultations, stakeholder workshops, and literature reviews. The assigned weights reflect the impact of each parameter on the overall vulnerability of the population.

The next step involves calculating the Composite Vulnerability Index (CVI) for each area. The CVI is calculated using the formula $CVI=\sum(Wi \times Ni)$, where Wi represents the weight of parameter i, and Ni represents the normalized value of parameter i. This index integrates the weighted parameters to provide a comprehensive vulnerability score for each area.

Each parameter in the assessment has a specific impact on vulnerability. Higher literacy rates indicate higher coping capacity and thus lower vulnerability. Conversely, higher population density and greater numbers of household's increase vulnerability due to the larger number of people and buildings at risk. Parameters such as the sex ratio and the population of children aged 0-6 highlight specific vulnerable groups. Additionally, poor living conditions, indicated by households without electricity, inadequate drainage, unhygienic drinking water sources, and substandard housing materials significantly increase vulnerability. Social and economic vulnerability assessment of the states have provided in Figure 6-2 and Figure 6-3.

6.4 Multi-Hazard Risk Index

The assessment of the Multi-Hazard Risk Index (MHRI) involves a systematic approach to identify, evaluate, and map the risk posed by various hazards in a specific area. The process begins with the identification of major hazards, which may include natural events such as floods, landslides, earthquakes, and cyclones, as well as man-made hazards like industrial accidents and fires. Comprehensive data collection follows, utilizing historical records, government reports, satellite imagery, field surveys, and expert consultations to gather information on the frequency, intensity, and impact of each identified hazard.

Assigning weightage to each hazard is a critical step and is based on consultations with local resource groups and subject matter experts. These consultations help incorporate local knowledge and historical context. The weightage assignment considers three main factors: the probability of each hazard occurring, the potential impact on human life, property, and the environment, and the estimated *economic damage. Each factor is carefully evaluated to ensure a holistic understanding of the risk.*

Once weightages are assigned, the Composite Risk Index (CRI) for each area is calculated using the formula CRI=∑(Wi×Ri), where Wi represents the weightage of hazard i and Ri represents the risk score of hazard i. This formula integrates the various weighted hazards to provide a comprehensive risk score for each locality.

The final step is mapping the CRI using Geographic Information System (GIS) tools. The resulting map visually represents the different risk levels across the region, using a color-coded system: blue for no risk, green for low risk, yellow for moderate risk, and red for high risk. This visual representation aids in identifying high-risk areas that require focused disaster management and mitigation strategies, such as infrastructure strengthening, early warning systems, and community preparedness programs. Moderate risk areas need regular monitoring and periodic review of hazard mitigation plans, while low-risk areas should maintain existing safety measures and ensure readiness for any potential hazard escalation. By systematically assessing and mapping the multi-hazard risks, local governments can effectively prioritize resources, implement targeted mitigation strategies, and enhance community resilience against multiple hazards. The MHRI thus serves as a vital tool in disaster risk management, facilitating informed decision-making and proactive planning to safeguard communities. The MHRI map of the state has given in Figure 6-4.

6.4.1 Key Observations:

- *Northern Kerala (Kasaragod, Kannur, Wayanad): Shows a mix of low to high-risk areas, indicating variability in hazard exposure and impact.*
- *Central Kerala (Kozhikode, Malappuram, Palakkad, Thrissur, Ernakulam): Displays significant high-risk zones, particularly in regions prone to flooding and landslides.*
- *Southern Kerala (Alappuzha, Kottayam, Idukki, Pathanamthitta, Kollam, Thiruvananthapuram): Also shows considerable high-risk areas, especially in coastal and hilly regions.*

6.4.2 Implications:

***High-Risk Areas**: Need focused disaster management and mitigation strategies. This could include infrastructure strengthening, early warning systems, and community preparedness programs.*

***Moderate Risk Areas**: Require regular monitoring and periodic review of hazard mitigation plans.*

***Low Risk Areas**: Should maintain existing safety measures and ensure readiness for any potential hazard escalation.*

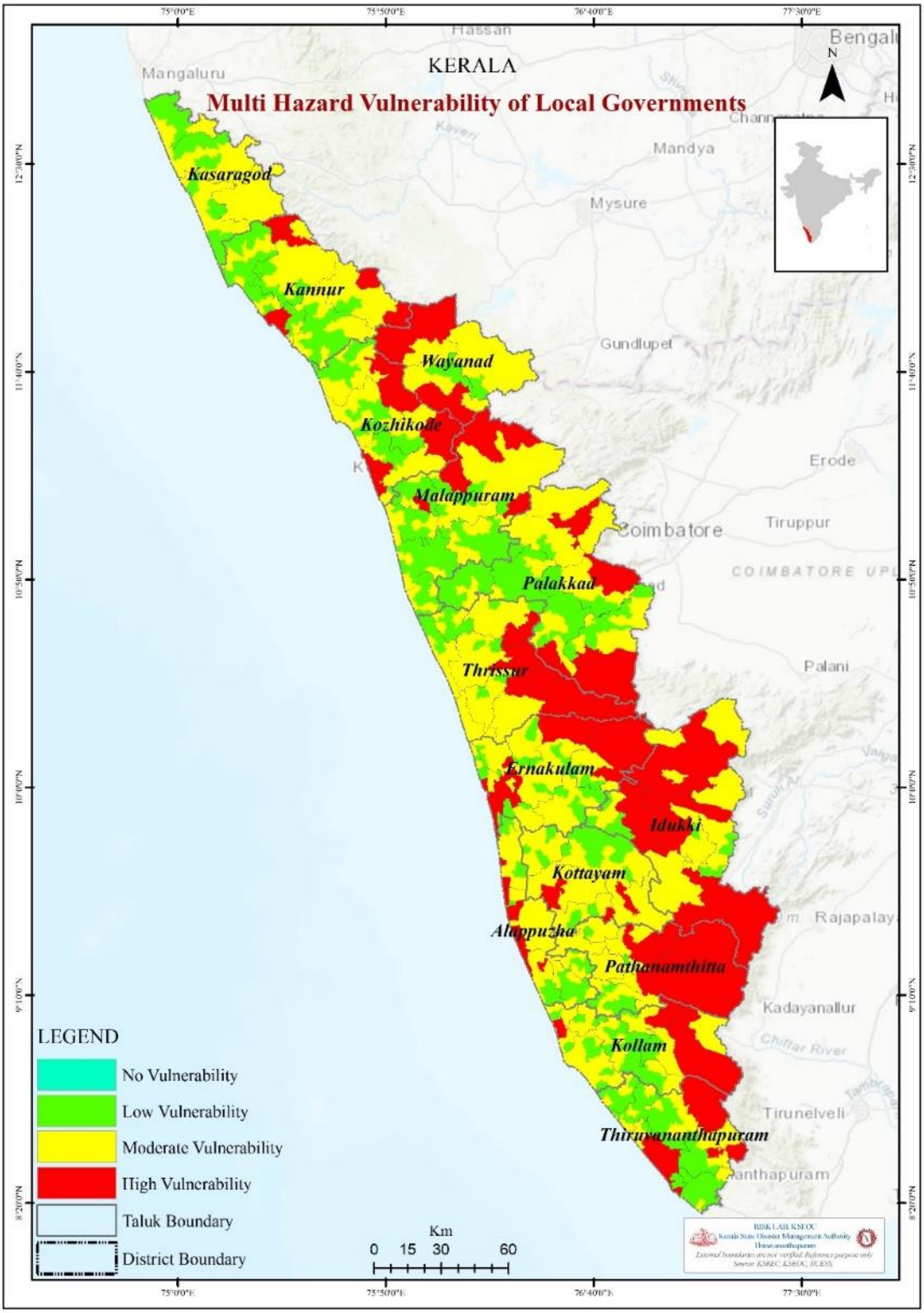


Figure 6-1: Multi-hazard vulnerability map of Kerala (Source: KSDMA)

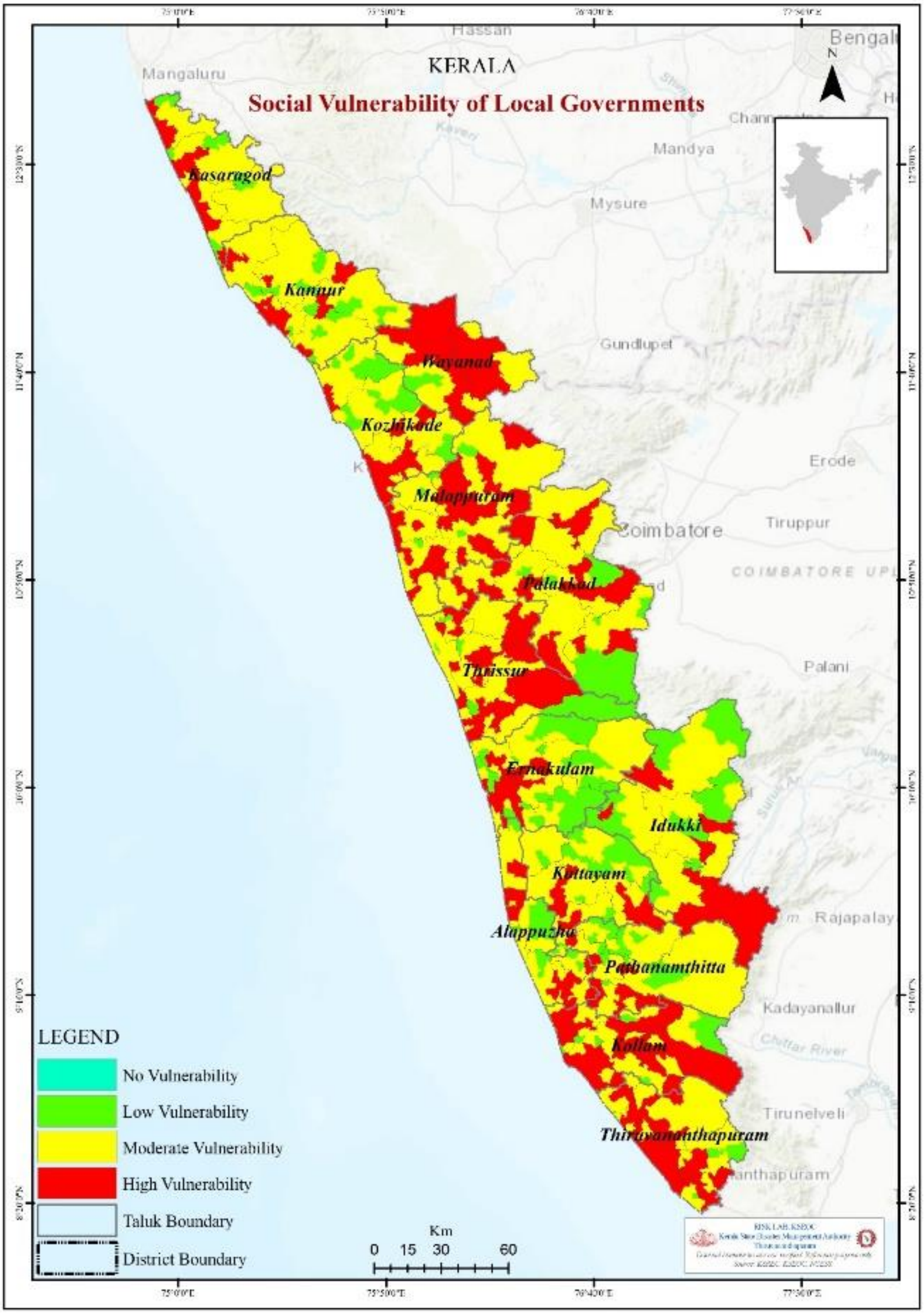


Figure 6-2: Social vulnerability maps of Kerala (Source: KSDMA)

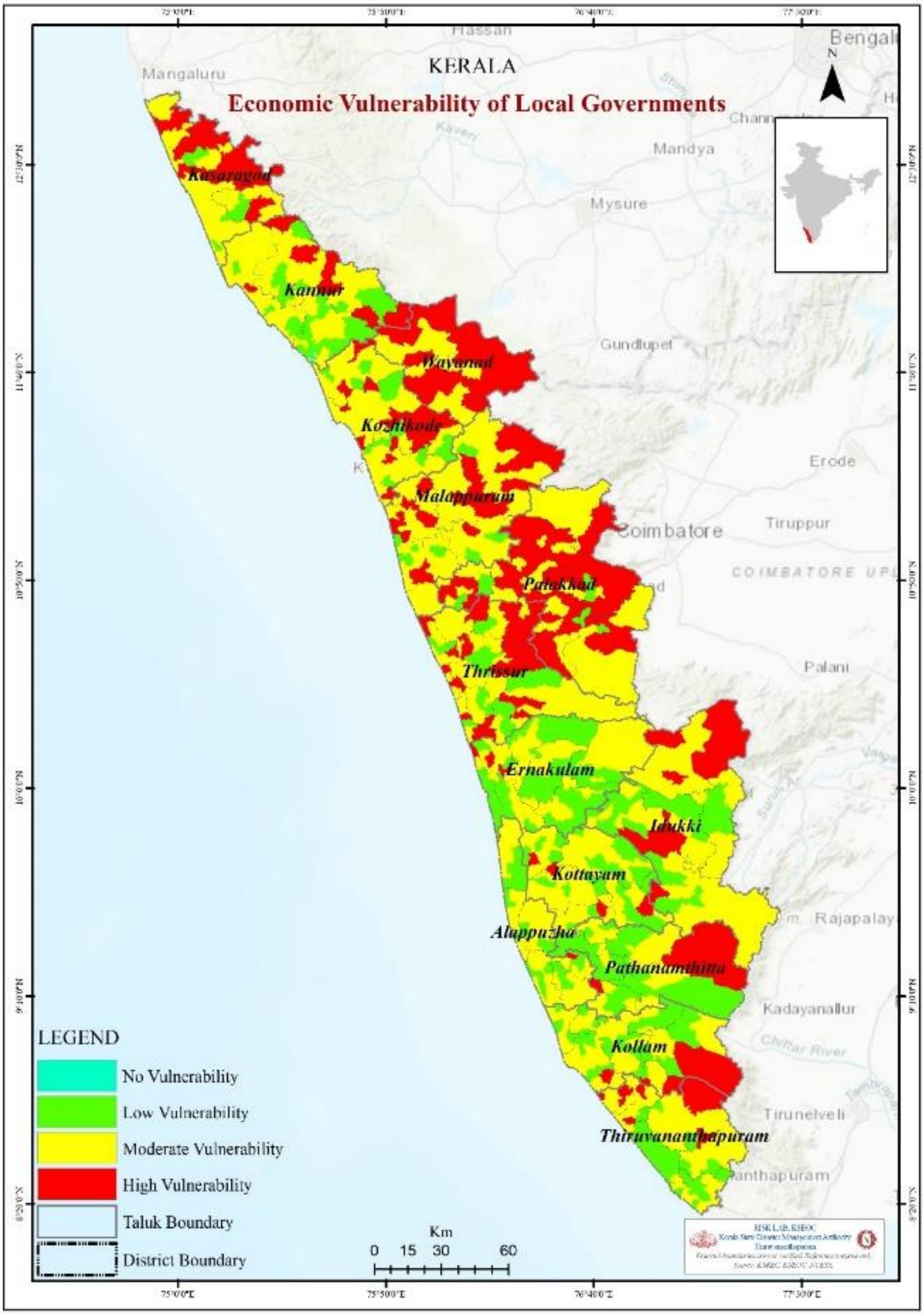


Figure 6-3: Economical vulnerability maps of Kerala (Source: KSDMA)

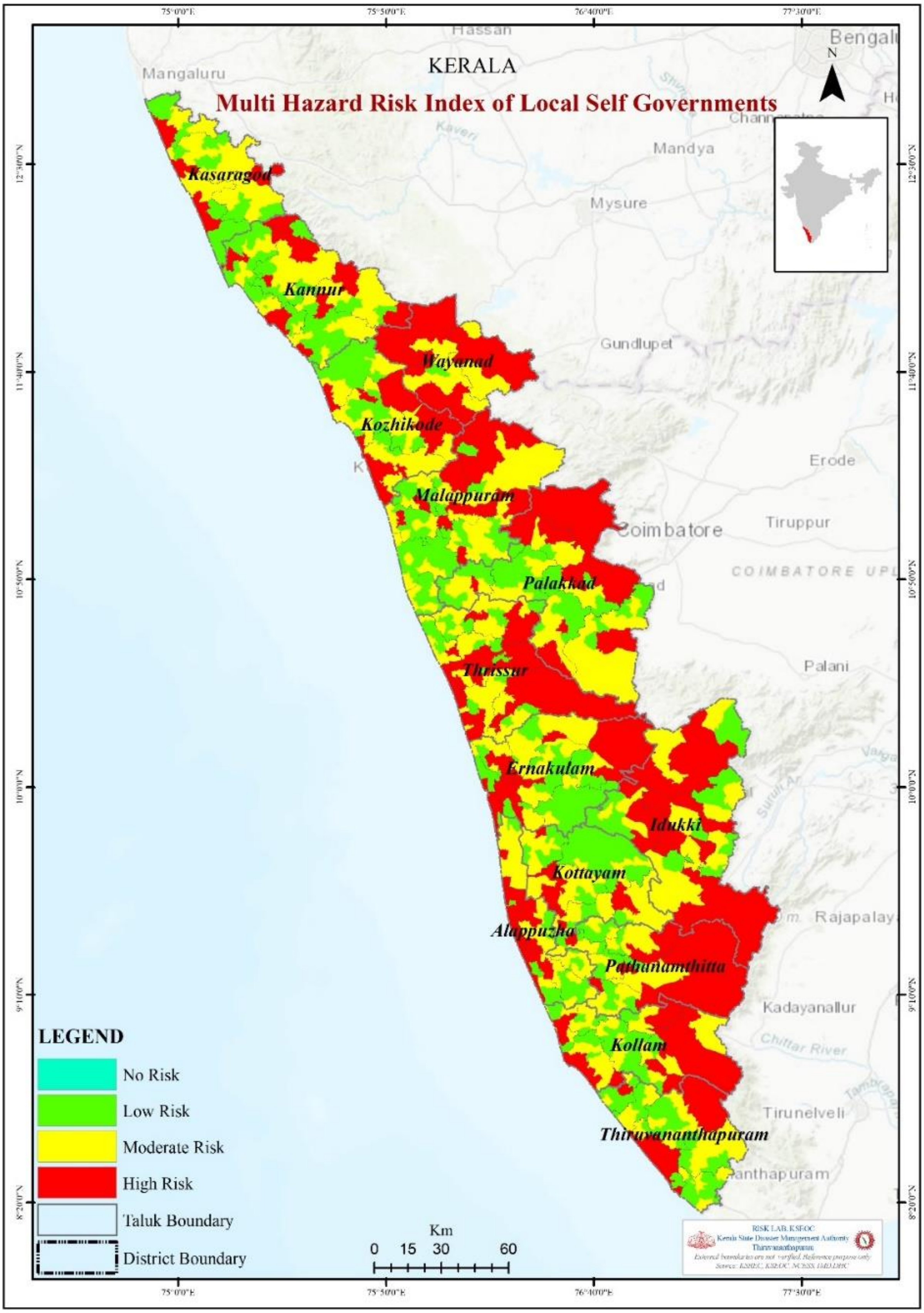
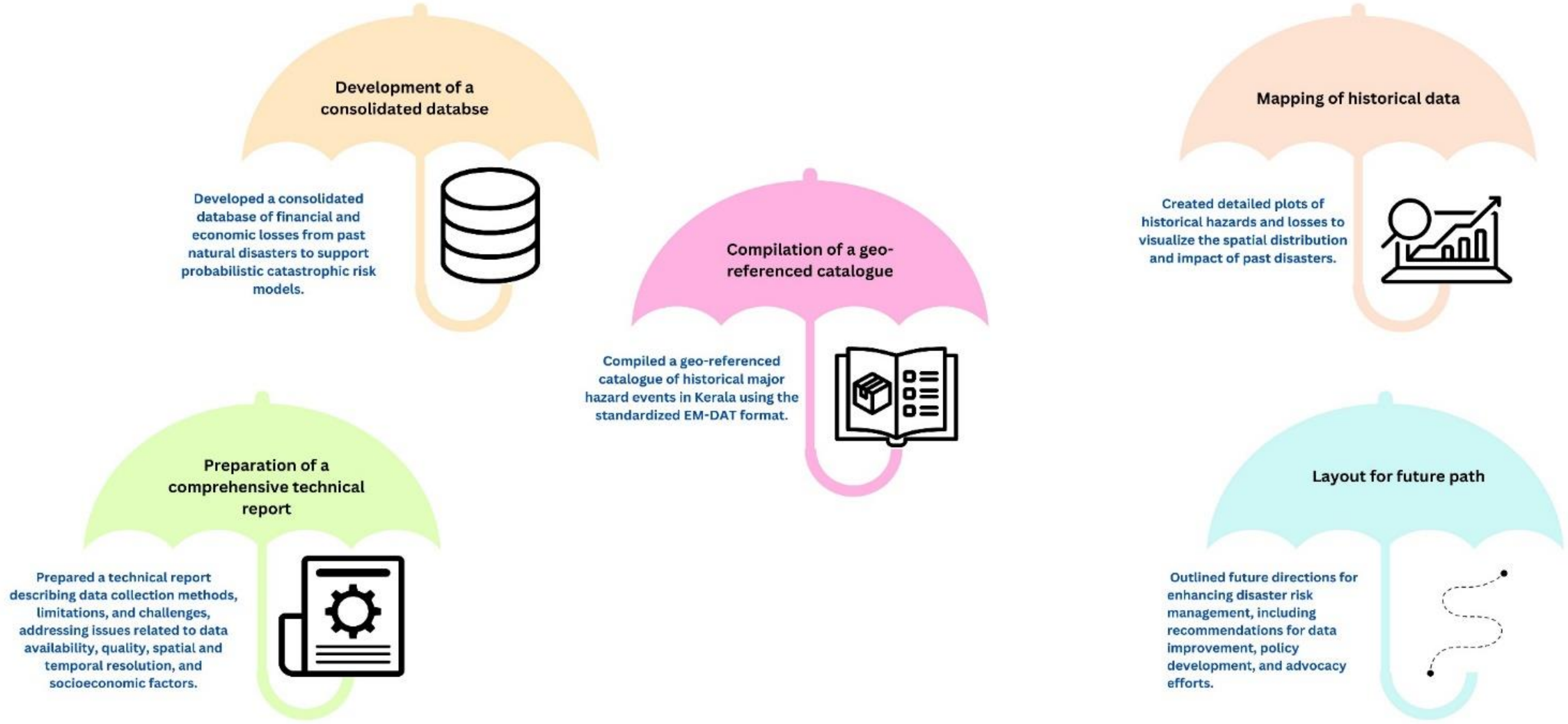


Figure 6-4: Multi Hazard Risk Index map of Kerala (Source: KSDMA)

7 Summary

7.1 Summary of Activities- the Kerala Project undertook the following key activities.



8 Annexure 1

8.1 Projection coordinates information

As RMSI has received all the database requirements from the client in "WGS_1984_UTM_Zone_43N" projection system, and will use the same for future projections and map preparations to deliver to the client.

8.2 Cyclonic Disturbances and Reported Losses, 1891-2023

Table 8-1: List of cyclonic disturbances in and around Kerala during (1891-2023)

S. No.	Type of Disturbance	Day	Month	Year	Maximum wind speed (km/h)
1	Very Severe Cyclonic Storm	05	11	1898	119
2	Cyclonic Storm	30	12	1908	83
3	Very Severe Cyclonic Storm	19	11	1912	119
4	Very Severe Cyclonic Storm	15	10	1916	119
5	Very Severe Cyclonic Storm	01	11	1919	119
6	Very Severe Cyclonic Storm	25	11	1922	119
7	Very Severe Cyclonic Storm	06	11	1925	119
8	Cyclonic Storm	05	05	1930	83
9	Deep Depression	20	05	1932	56
10	Very Severe Cyclonic Storm	11	11	1935	119
11	Deep Depression	12	11	1940	56
12	Very Severe Cyclonic Storm	30	11	1941	119
13	Cyclonic Storm	09	12	1941	83
14	Cyclonic Storm	31	10	1946	65
15	Cyclonic Storm	14	11	1946	65
16	Very Severe Cyclonic Storm	17	11	1958	120
17	Depression	27	11	1959	46
18	Depression	09	11	1961	46
19	Cyclonic Storm	13	05	1962	65
20	Cyclonic Storm	05	12	1965	65
21	Very Severe Cyclonic Storm	31	10	1966	120
22	Very Severe Cyclonic Storm	07	11	1966	120
23	Very Severe Cyclonic Storm	01	12	1972	120
24	Very Severe Cyclonic Storm	03	11	1978	148
25	Very Severe Cyclonic Storm	19	11	1978	167
26	Cyclonic Storm	10	10	1980	65
27	Severe Cyclonic Storm	25	10	1981	111
28	Very Severe Cyclonic Storm	27	11	1984	213
29	Severe Cyclonic Storm	11	11	1992	102
30	Depression	08	11	1993	46
31	Deep Depression	02	11	1997	56

S. No.	Type of Disturbance	Day	Month	Year	Maximum wind speed (km/h)
32	Extremely Severe Cyclonic Storm	26	11	2000	189
33	Very Severe Cyclonic Storm	23	12	2000	167
34	Very Severe Cyclonic Storm - Ockhi	29	11	2017	157
35	Very Severe Cyclonic Storm - Gaja	10	11	2018	130
36	Extremely Severe Cyclonic Storm - Tauktae	14	05	2021	185

Table 8-2: Loss details due to extreme cyclone events during (1891 -2023) for Kerala

S. No.	Date	Landfall Location	Damage Details
1	November 13 - 23, 1977 (Severe Cyclonic Storm)	Crossed between Mangalore and Honavar, Maharashtra	Kerala, Lakshadweep, and Maharashtra were affected due to this storm; 72 people were killed; 8,400 houses were damaged, and 620 fishing vessels were damaged in Kerala coast; total loss was estimated to be about INR 10 crores[46].
2	November 4, 1978 (Deep Depression)	Crossed Tamil Nadu coast near Cuddalore	About 50 persons died in Kerala due to floods; considerable damage to crops and houses were reported from Tamil Nadu and Kerala[47]
3	November 11-17, 1992 (Severe Cyclonic Storm)	Crossed Karnataka coast near Honavar	According to the press reports about 175 persons lost their lives and 160 people reported missing in Tamil Nadu and Kerala; heavy rains caused flash floods and landslides resulting in considerable damage to the standing crops and houses in Karnataka, Kerala, and Tamil Nadu[48,33]
4	29 Nov - 05 Dec, 2017 (Very Severe Cyclonic Storm Ockhi)	Crossed Sri Lanka coast and then crossed south Gujarat coast between Surat and Dahanu	Damage over Kerala: As per report published by KSDMA, Kerala state witnessed loss of lives of 51 persons, 234 injured, and 9,134 affected. About 3,744 houses were damaged by cyclone Ockhi in Kerala[49,50]
5	14^{th} -19^{th} May, 2021 (Extremely Severe Cyclonic Storm Tauktae)	Crossed Gujarat coast near Diu	As per the report published by KSDMA,11 people lost their lives, 22 injured, 7,063 affected and a total of 4,419 houses were damaged in Kerala[51]

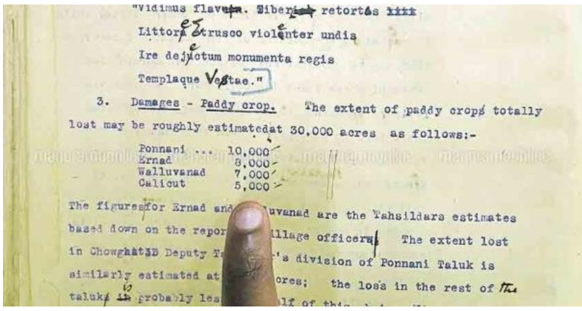
[46] SMRC (1998). The impact of tropical cyclones on the coastal regions of SAARC countries and their influence in the region, SMRC-No.1, SAARC Meteorological Research Centre, Dhaka, Bangladesh, October 1998, 329 pp.
[47] Srinivasan, V., Ramakrishnan, A. R., & Jambunathan, R. (1980). Cyclones and depressions in the Indian seas in 1978. MAUSAM, 31(4), 495-506.
[48] IMD Report on cyclonic disturbances over North Indian Ocean in 1992- RSMC Tropical Cyclones (1993)
[49] Memorandum-Ockhi-2017 by Additional Chief Secretary, Disaster Management, Govt. of Kerala (KSDMA).
[50] IMD Report: 2018, Very Severe Cyclonic Storm, 'OCKHI' over the Bay of Bengal (29 Nov.-05 Dec. 2017)
[51] An Integrated Approach to the Preparedness and Mitigation of Cyclone Tauktae: The Case of Kerala: 2021(KSDMA).

9 Annexure 2-

9.1 Flood and Landslide Photographs

July and August flooded most part of Travancore, Kochi, and Malabar in 1924

Roads and bridges washed away in the floods of 1924



Incessant rain caused widespread damage; the documents prove in 1924

Water level marked at Chaliyar river below Feroke bridge during the 1961 floods

Figure 9-1: Few photographs of flood incidents during 1924 and 1961 floods (Source: Manorama[52])

[52] https://www.onmanorama.com/news/kerala/2018/08/22/kerala-people-escape-99-floods-kozhikode-kochi.html

Figure 9-2: Landslides in different parts of Idukki district caused due to the removal of toe for construction of road. a) Cheruthoni, b) Irumbupalam, c) Chinnakanal, d) Cheeyapara, e) Kirithodu, f) Munnar, g) Adimall and h) Kallar (Modified after GIS 2013 report)

Figure 9-3: Landslides in different parts of Idukki district caused due to the heavy rainfall a) Cheruthoni, b) Irumbupalam, c) Chinnakanal, d) Cheeyapara, e) Kirithodu, f) Munnar, g) Adimall and h) Kallar (Modified after GIS 2013 report)

Figure 9-4: Various photographs depicting damages due to landslides and floods in Kerala, 2012

Figure 9-5: Arial view of the Kootickal landslide location

Figure 9-6: Landslide location at Kokkayar where rescue operations are carried out

Figure 9-7: Photograph showing a destroyed house at Kootickal

Figure 9-8: Rescue operations carried out at the landslide location near Mackochi in Kokkayar village

Figure 9-9: A car struck in mud at Pampa, Triveni (Source: The New Indian Express 01st Dec 2017)-IMD Report (2018)

Figure 9-10: A tree fell over auto rickshaw at Sreekanteshwaram in Thiruvananthapuram[53]

Figure 9-11: Tree falls observed in Thiruvananthapuram, (Source: United News of India, Thiruvananthapuram dated 30th Nov; IMD Report (2018)

53 Source:http://english.mathrubhumi.com/news/kerala/cyclone-ockhi-closes-in-on-kerala-coast-1.2424815)-IMD Report (2018)

Figure 9-12: Indian Navy in the coastal village of Chellanam in Ernakulam district, Kerala (left) which was heavily hit by tidal waves; House Collapses into the sea in Kasaragod, Kerala due to the effect of Cyclone Tauktae (right) (Source: IMD Report, 2021)

Figure 9-13: House damaged in Malappuram district due to Cyclone Tauktae (Source: District Emergency Operations Centre, Malappuram) (left); House damaged in Palakkad district due to Cyclone Tauktae (Source: District Emergency Operations Centre, Palakkad) (right) (Source: KSDMA)

RMSI Pvt. Ltd.
A-8, Sector 16
Noida 201301, INDIA
Tel: +91-120-251-1102, 2101
Fax: +91-120-251-1109, 0963
www.rmsi.com