Government of the People's Republic of Bangladesh
Department of Disaster Management
Ministry of Disaster Management and Relief

M ULTI HAZARD
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A SSESSMENT,
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FINAL REPORT OF MULTI HAZARD RISK AND VULNERABILITY ASSESSMENT, MODELING AND MAPPING IN BANGLADESH

VOLUME II: GEOLOGICAL AND ENVIRONMENTAL HAZARD ASSESSMENT

EARTHQUAKE, TSUNAMI, TECHNOLOGICAL AND HEALTH

Government of the People's Republic of Bangladesh

Draft Final Report on Multi-Hazard, Vulnerability and Risk Assessment in Bangladesh

Volume – II: Geological and Environmental Hazard Assessment

(Earthquake, Tsunami, Technological and Health)

Department of Disaster Management
Ministry of Disaster Management and Relief

Message from Secretary, MoDMR

Government of the Peoples' Republic of Bangladesh had initiated the 'Emergency 2007 Cyclone Recovery and Restoration Project (ECRRP)' under DDM, LGED & BWDB with the assistance of the World Bank for Disaster Risk Mitigation and Reduction. Multi-hazard Risk and Vulnerability Assessment, Modeling and Mapping (MRVAM) is one of the initiatives under ECRRP, D1(DDM component) to assess risk and vulnerability of 8(eight) major hazards like Flood, Cyclone induced Storm Surge, Landslide, Drought, Earthquake, Tsunami, Technological & Health hazards. Component D1 is designed to contribute towards 'building long-term preparedness by strengthening disaster risk management' through strengthening and enhancement of long-term disaster risk mitigation and reduction ability of the DDM. This study is very important, due to the geographical location and topographical features of Bangladesh, exposed the country to almost all kinds of natural disasters and a large-scale disasters in Bangladesh has been observed at a frequency of 5-6 years.

I am very happy to know that ECRRP-D1 project is going to publish comprehensive Report on MRVAM with the help of ADPC, Thailand and IWM, Bangladesh. This study will supplement the efforts of the government to incorporate disaster risk reduction issues in all development programmes to build a safe and disaster resilience nation, referring to the SOD-2010, Disaster Management Act-2012, Disaster Management Policy-2015, and National Disaster Management Plan 2010-15. Alongside by the government, all including non- governmental organizations (NGOs) and civil society should come forward to build an effective disaster management infrastructure to reduce the post-disaster losses. District and local level officials who are frequently involved with the disaster damage assessment, management, preparedness and risk & vulnerability reduction activities will be benefitted by using these national level risk assessment map and database from this project.

Md. Shah Kamal
Secretary
Ministry of Disaster Management and Relief

Message from DG, DDM

Bangladesh has made a strong commitment to implement Hyogo Framework for Action (HFA) during 2005-2015 for critical guidance in efforts to reduce disaster risk and the Multi-Hazard Risk and Vulnerability Assessment, Modeling and Mapping (MRVAM) project initiated under 'Emergency 2007 Cyclone Recovery and Restoration Project (ECRRP)' as D1 component has advanced Bangladesh's progress in Priority Action 2: Identify, assess and monitor disaster risks and enhance early warning. In continuation of this, outcome of this project "Multi-Hazard Risk Assessment at national level" is in line with Priority 1: 'Understanding disaster risk' of Sendai Framework for Disaster Risk Reduction 2015-2030, adopted in the 3rd World Conference on Disaster Risk Reduction, held from 14 to 18 March 2015 in Sendai, Miyagi, Japan.

The findings of MRVAM project has create the basis for "building long term preparedness through strengthening disaster risk management capacity in the country as well as for enhancement of long term disaster risk mitigation and reduction ability of the Department of Disaster Management (DDM)". On the other hand, MRVAM project outcome has created awareness among the district and upazila level officials and will help in contributing towards incorporating appropriate risk-reduction strategies and prioritizing them into the country's development planning process.

In addition to this, the findings of this study 'risk information of population, housing and livelihood at upazila level' will allow decision makers to prioritize risk mitigation investments and measures to strengthen the emergency preparedness and response mechanisms for reducing the losses and damages due to future disaster events.

(Md. Reaz Ahmed)
Director General (Additional Secretary)
Department of Disaster Management

Message from PD, ECRRP-D1, DDM

Multi-Hazard Risk and Vulnerability Assessment, Modeling and Mapping (MRVAM) project implemented as a part of sub-component D1.2 ‘Emergency 2007 Cyclone Recovery and Restoration Project (ECRRP)’, by Department of Disaster Management (DDM) is an efforts towards ‘building long-term preparedness through strengthened disaster risk management’, through the strengthening and enhancement of the long-term disaster risk mitigation and reduction ability of the DDM.

This project has developed enormous quantity of database representing multi-hazards of Flood, Cyclone induced Storm Surge, Landslides, Drought, Earthquake, Tsunami, Technological and Health along with national level database representing population, housing, livelihood, critical facilities, infrastructure which can be used at Union / Upazila level for development planning process.

DDM has established Multi-Hazard Risk and Vulnerability Assessment (MRVA) Cell, in which geo-database of hazard, exposure and risk assessment at upazila level developed in this project and hosted in the state of the hardware & software facilities. I take this opportunity to state that, this will enhance the capacity of the department to monitor the hazard, exposure and risk assessment, in this way, all the government agencies, professionals and researchers will be benefitted in contributing towards disaster risk reduction in Bangladesh.

(M. Khalid Mahmood)
Joint Secretary and Director (Planning & Development)
Project Director, ECRRP-D1
Department of Disaster Management

Preface

A category IV cyclone *SIDR* struck in the south west coast of Bangladesh on November 15, 2007 evening and moved inland, destroying infrastructure, causing numerous deaths, disrupting economic activities, and affecting social conditions. As most all of Bangladesh is considered as a Delta just above sea level, tidal surge of 15-20 feet and gail-force winds of approximately 150 mph creates havoc in most of the area. The aim of the assessment was to identify priority areas to support the Government of Bangladesh in cyclone recovery efforts as well as to recommend priority interventions for a long-term disaster management strategy. The preparation of Multi-Hazard Risk and Vulnerability Assessment, Modelling and Mapping (MRVAM) project has identified the damage needs and quantified financial and technical requirements and established MRVA Cell in DDM, that will facilitate formulating comprehensive early recovery actions, medium-term recovery and reconstruction plans and a long-term disaster risk management and reduction strategy. The main objective to establish MRVA Cell is to strengthen and enhance country capacity in carrying out systematic multi-hazard risk assessments and consolidating and maintaining hazard risk information at central (national) and disaggregated (district) levels. This will contribute towards the realization of the specific priority attached in the country's disaster management strategy of 'defining and redefining the risk environment' of the country. The Asian Disaster Preparedness Center (ADPC), Thailand, in partnership with the Institute of Water Modeling (IWM), the Norwegian Geotechnical Institute (NGI), the Asian Institute of Technology (AIT), and the Faculty of Geo-Information Science and Earth Observation of the University of Twente (ITC), the Netherlands have been worked together to deliver consulting services on the Multi-Hazard Risk and Vulnerability Assessment, Modeling and Mapping in Bangladesh and finally have prepared the Volume I: Hydro-meteorological Hazard Assessment (Flood, Storm Surge, Landslide, Drought), Volume II: Geological and Environmental Hazard Assessment (Earthquake, Tsunami, Technological, Health), Volume III: Elements at risk, Volume IV: Vulnerability and Risk Assessment (Flood, Storm Surge, Landslide, Drought), Volume V: Vulnerability and Risk Assessment (Earthquake, Tsunami, Technological, Health), Volume VI: Summary and Recommendations.

For flood hazard and vulnerability assessment, Flood Modeling used in this study is MIKE11 Hydrodynamic Model developed by DHI, coupled with Geographic Information System (GIS) to capture the hydraulic response of Bangladesh Rivers, in-depth Flood analysis and its floodplains in extreme flooding conditions. Then a frequency analysis was carried out in the river network at 7617 grid points in order to obtain return period-wise flood levels for 25 year, 50 year, 100 year and 150 years. The model used in MRVAM project for Cyclone induced Storm Surge is called Bay of Bengal Model (BoBM). The model is developed using a MIKE21 FM modelling system, which is a numerical modelling system for the simulation of water levels and flows in estuaries, bays and coastal areas. Storm Surge hazard depth was divided into seven different depth categories in order to find the extent of surge inundation and prepare inundation maps for all return periods: 25, 50 and 100 years for the entire coastal region. The depth categories are <1 m, 1-1.5 m, 1.5-2 m, 2-3 m, 3-4 m, 4-5 m, >5 m. Earthquake hazard maps were developed using the historical data and existing geological setting for 50 year, 100 year, 200 year, 500 year and 1000 years return periods at the sites of investigation derived and interpolated to develop earthquake hazard maps representing spatial variation of Peak Ground Acceleration (PGA) Map in Bangladesh.

Simultaneously, to model the tsunamigenic conditions and the possible hazard maps due to Tsunami, have been generated for 50, 100, 200, 500 and 1000 years return period and the SPI (Standardized Precipitation Index)-Return period plots used to calculate the severity of Drought with different return periods such as the SPI values for 10, 50 and 100 years return period.

The purpose of this Multi-Hazard Risk and Vulnerability Assessment (MRVA) Modelling and Mapping study is to develop a hazard and vulnerability framework using the progression of vulnerability model to identify the root causes (problems) and the underlying pressures within coastal belt as well as whole Bangladesh. The information provided in this study was intended to assist in identifying hazards and vulnerabilities thereby building a disaster resilient Districts and Upazilas by sharing local hazards and also establishing community structures. Combining the results of the theoretical framework and research findings with the argument constructed in these Volumes I-VI about the disaster risk reduction and mitigation; it was found that it is possible to reduce hazard risks, and vulnerability to disasters, through the application of the latest GIS & RS tools and Hydrodynamic modeling and the participation of the grass-root level community in disaster risk management activities.

It is a great pleasure to successfully launch this Scientific MRVA National Document, signifying the needs and opportunities for the protection of the coastal environment as well as overall most vulnerable districts of Bangladesh and associated lives and livelihoods. The Department of Disaster Management (DDM), Ministry of Disaster Management and Relief would like to thank all those involved in the preparation and finalization of this document and would like to believe that materialization of these policies and programmes will improve overall catastrophic environment of the country as a whole and coastal environment in particular.

We would like to express our in-depth gratitude to the prominent experts of Technical Advisory Committee (TAC), the well-known and reverend group of professionals of the Country, specially, Dr. A. S. M. Maksud Kamal, Convener-TAC and Dean, Faculty of Earth and Environmental Sciences, Dhaka University; Dr. Umme Kulsum Navera, Professor, Department of Water Resources Engineering, BUET; Dr. Md. Atiqur Rahman, Joint Secretary (Admin.), Ministry of Disaster Management and Relief (MoDMR), Mr. M. A. Rouf Hawlader, Director, Survey of Bangladesh; Mr. Shamsuddin Ahmed, Director in Charge, Bangladesh Meteorological Department (BMD), Mr. Md. Shahidul Islam, GIS Analyst, CDMP-II; Mr. Mir Ahmed, Member Secretary-TAC & Director-MIM, DDM; Mr. M. Khalid Mahmood, Director (Planning & Development) & PD-ECRRP-D1, DDM; and Mr. Reaz Ahmed, Director General and MRVAM Advisor, DDM & last of all, those associated with MRVA Cell; under whose overall guidance and supervision, these MRVA Volumes were duly checked and scientifically verified, who had worked relentlessly for years to generate scientific information required for these risk and vulnerability assessments. A special appreciation to the World Bank, ERD and PCMU – Planning Commission Team, whose financial and project extension support from the beginning helped us to reach its ultimate destination.

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List of Abbreviations

ADPC	Asian Disaster Preparedness Center
AEGL	Acute Exposure Guideline Levels
AFCLL	Ashuganj Fertilizer and Chemical Company Limited
ALOHA	Areal Locations of Hazardous Atmospheres
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BCIC	Bangladesh Chemical Industries Corporation
BGD	Back Ground Deep
BGI	Back Ground Intermediate
BGS	Back Ground Shallow
BISF	Bangladesh Insulator & Sanitary Ware Factory Limited
BLEVE	Boiling Liquid Expanding Vapor Explosion
BMD	Bangladesh Meteorological Department
BNBC	Bangladesh National Building Code
BPC	Bangladesh Petroleum Corporation
BSCIC	Bangladesh Small and Cottage Industries Corporation
BSEC	Bangladesh Steel Engineering Corporation
BSFIC	Bangladesh Sugar and Food Industries Corporation
CAMEO	Computer-Aided Management of Emergency Operations
CaO	Calcium Oxide
CCCL	Chhatak Cement Company Limited
CDMP	Comprehensive Disaster Management Programme
CLP	Classification, Labelling and Packaging
CNG	Compressed Natural Gas
COMCOT	Cornell Multi-grid Coupled Tsunami Model
CSCL	Chemical Substances Control Law
CUFL	Chittagong Urea Fertilizer Limited
DAPFCL	DAP Fertilizer Company Limited
DEM	Digital Elevation Model
DGHS	Directorate General of Health Services
EHSs	Extremely Hazardous Substances
EPA	Environmental Protection Agency
EU	European Union
FACTS	Failure and Accidents Technical Information System
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Oceans
GHS	Globally Harmonized System
GIS	Geographic Information System
GMPEs	Ground Motion Prediction Equations
GPS	Global Positioning System
GRIP	Global Risk Identification Program

HFT	Himalayan Frontal Thrust
HSS	Himalayan Strike Slip
IWM	Institute of Water Modeling
JFCL	Jamuna Fertilizer Company
JPL	Jet Propulsion Laboratory
KPM	Karnaphuli Paper Mills Limited
LIDAR	Light Detection And Ranging
LOC	Level of Concerns
MARPLOT	A mapping *program* developed jointly by NOAA and EPA for CAMEO site.
MC	Magnitude of Completeness (Earthquake Catalogue)
MHWS	Mean High Water Spring
MMI	Modified Mercalli Intensity
MoDMR	Ministry of Disaster Management and Relief
MoHFW	Ministry of Health and Family Welfare
MOI	Ministry of Industries
MRVA	Multi-Hazard Risk and Vulnerability Assessment
MRVAM	Multi-Hazard Risk and Vulnerability Assessment, Modelling and Mapping
MW	Moment Magnitude
NOS	Nitrous Oxide
NaOH	Caustic Soda
NGA	Next Generation Attenuation
NGFFL	Natural Gas Fertilizer Factory Limited
NGO	Non-Government Organization
NOAA	National Oceanic and Atmospheric Administration
PGA	Peak Ground Acceleration
POP	Persistent Organic Pollutants
PUFFL	Polash Fertilizer Factory Limited
PVC	Polyvinyl chloride
SA	Spectral Acceleration
SD	Sub-duction
SRTM	Shuttle Radar Topography Mission
ToR	Terms of Reference
TNO	Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)
TSCA	Toxic Substances Control Act
TSP	Trisodium Phosphate
TSPCL	TSP Complex Limited
UFFL	Urea Fertilizer Factory Limited
UGSF	Usmania Glass Sheet Factory Limited
UN	United Nations
UNDP	United Nations Development Program
UNECE	United Nations Economic Commission for Europe

UNISDR	United Nations International Strategy for Disaster Reduction
USD	US Dollar
USGS	United States Geological Survey
YPSA	Young Power in Social Action

Multi-Hazard Risk and Vulnerability Assessment (MRVA) Report

Volume II: Geological and Environmental Hazard Assessment

Chapter 1: Hazard Assessment

Hazard assessment is the first step towards risk assessment. Hazard assessment includes severity, frequency, and the geographical extent of influence and any warning signs it provides. In this study, eight hazards were considered based on the terms of reference (ToR), namely Flood, Cyclone induced Storm Surge, Landslide, Drought, Earthquake, Tsunami, Technological and Health. Among the eight hazards, four hazards, flood, cyclone storm surge, landslide, and drought are presented in Volume I of this report and the remaining four hazards, earthquake, tsunami, technological and health are presented in this Volume II of this report.

1.1 Background

1.1.1 Characteristics of Hazard Assessment

Hazard Assessment consists of determining the following:

- When and where hazardous processes have occurred in the past;
- The severity of the physical effects of past hazardous processes (magnitude);
- The frequency of occurrence of hazardous processes;
- The likely effects of a process of a given magnitude if it were to occur now; and
- Making all this information available in a form useful to planners and public officials responsible for making decisions in the event of a disaster.

1.1.2 Scope of Hazard Assessment in this Project

The identified hazards in this project, namely flood, cyclone storm surge, earthquake, tsunami, landslide, drought, technological and health have been assessed keeping the above-mentioned aspects in mind. Some hazards such as earthquake and tsunami indirectly affect Bangladesh due to the geographical and geological setting of neighboring countries such as India and Myanmar. These aspects are also considered in the hazard assessment. Technological hazards are assessed based on the available data from industries provided by Ministry of Industries and the chemical, which can cause damage to population and property in the neighborhood. Health hazard assessment is limited to the number of people affected due to most of the communicable diseases and also arsenicosis at the district level only, due to data limitation.

1.2 Earthquake

Bangladesh is located in the tectonically active Himalayan orogenic belt that developed by the collision among the Indian, Arabian, and Eurasian plates over the last 30-40 million years (Aitchinson et al., 2007). Moderate to large earthquake magnitudes are common in this region and will continue to occur as long as the tectonic deformation continues. Some of these earthquakes caused serious damage to buildings and infrastructures through strong ground shaking and also, in some cases, faults rupturing the ground surface. The destructive and deadly hazards associated with earthquakes pose a real and serious threat to the life of people, property damage, economic growth and development of the country. Therefore, proper understanding of the distribution and level of seismic hazard throughout the country is necessary, and hence a probabilistic seismic hazard assessment for Bangladesh has been carried out. The main objective of this work is to determine appropriate earthquake ground motion parameters for seismic mitigation based on the best available information. These ground motion parameters include: horizontal Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) values at 0.2 and 1.0 s with the return periods of 100, 200, and 1000 years.

1.2.1 Data Used and Methodology

The methodology adopted for the seismic hazard assessment follows the one used for developing the latest US National Seismic Hazard Maps (Petersen et al., 2008). Its basic steps can be briefly described as follows:

Step 1: is the modeling of earthquake sources. In this work, the earthquake sources in the study region are modeled by a combination of smooth gridded seismicity, crustal fault and sub-duction source models. Detailed descriptions of these earthquake source models are given in subsequent sections. The seismic activity of each of these sources is characterized by a magnitude-recurrence relationship, which shows the average occurrence rate of earthquakes of a given magnitude occurring inside the source. This step is the most important and most time consuming step in the assessment work.

Step 2: is the identification of models that can reasonably represent the attenuation characteristics of earthquake ground motions within the study region. By using these attenuation models (or 'ground motion prediction equations'), ground motion parameters such as PGA and SA at the site produced by an earthquake of a given magnitude occurring at a given location can be estimated.

Step 3: is the evaluation of the hazard at the site. The effects of all earthquakes of different magnitudes, occurring at different locations in different seismic sources at difference probabilities of occurrence are integrated into hazard curves. Each hazard curve shows the probability of exceeding different PGA or SA levels at the site during a specified period of time. From the obtained hazard curves, uniform hazard response spectra for various return periods at the sites of investigation can be derived.

The details of the seismic hazard assessment and its results are explained in the following sections.

1.2.1.1 Regional Tectonic Settings

Bangladesh, a densely populated country in South Asia, is located in the northeastern part of the Indian sub-continent at the head of the Bay of Bengal. Tectonically, Bangladesh lies in the northeastern Indian plate near the edge of the Indian craton and at the junction of three tectonic plates – the Indian plate, the Eurasian plate and the Burmese microplate. These form two boundaries where plates converge the India-Eurasia plate boundary to the north forming the Himalaya Arc and the India-Burma plate boundary to the east forming the Burma Arc. The Indian plate is moving ~6 cm/yr in a northeast direction and sub-ducting under the Eurasian (@ 45 mm/yr) and the Burmese (@ 35 mm/yr) plates in the north and east, respectively (Sella et al., 2002; Bilham, 2004; Akhter, 2010).

To the north, the collision between the Indian and Eurasian plates has created the spectacular Himalayan Mountains, bounded along their southern flank by the Himalayan Frontal Thrust (HFT), along which continental lithosphere of the Indian plate under thrusts the Eurasian plate (Figures 1.1 and 1.2). This great north-dipping thrust fault runs more than 2,000 km from Pakistan to Assam and has produced many large continental earthquakes over the past millennium, some greater than M 8. The 500-km long section just 60-km north of Bangladesh, however, has not produced a great earthquake in the past several hundred years (Kumar et al. 2010).

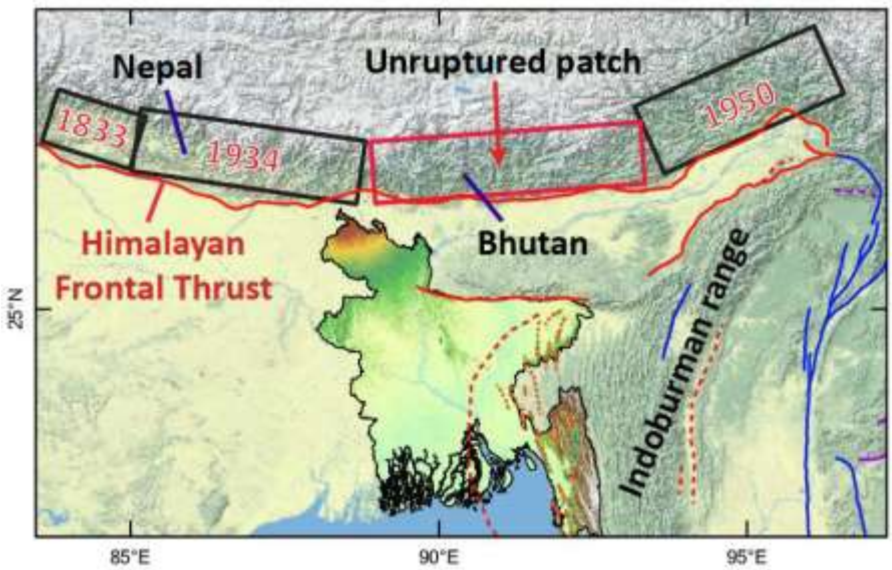


Figure 0.1: Approximate sources of four historical great earthquakes along the Himalayan Frontal Thrust fault.

Source: Wang and Sieh, 2013

The surface trace of the HFT and other major faults appear as a red line. Bangladesh is the region of colored topography. The latest complete rupture of the portion beneath Bhutan may have occurred between about 600 and 1000 years ago, perhaps about AD 1100, (Wang and Sieh, 2013).

The other major active tectonic belt of Bangladesh appears along the country’s eastern side. The Arakan subduction-collision system involves oblique convergence of the Indian and Burma plates. It has produced the N-S trending Indo-Burman range and a broad belt of folds along the western edge of the Bay of Bengal (Curray, 2005; Wang and Sieh, 2013). These lie above a mega thrust that dips moderately eastward beneath the Indo-Burman range but is nearly flat lying beneath the folds. Beneath the 500-km long fold belt the mega thrust is also referred to as a decollement, because it is parallel or nearly parallel to sediment bedding within the Ganges-Brahmaputra delta. As we will describe below, many of the folds within the western 100 to 200 Km of the fold belt appear to be actively growing, which implies that the underlying decollement is relaying slip onto thrust faults beneath these folds as it dies out westward toward a poorly defined deformation front.

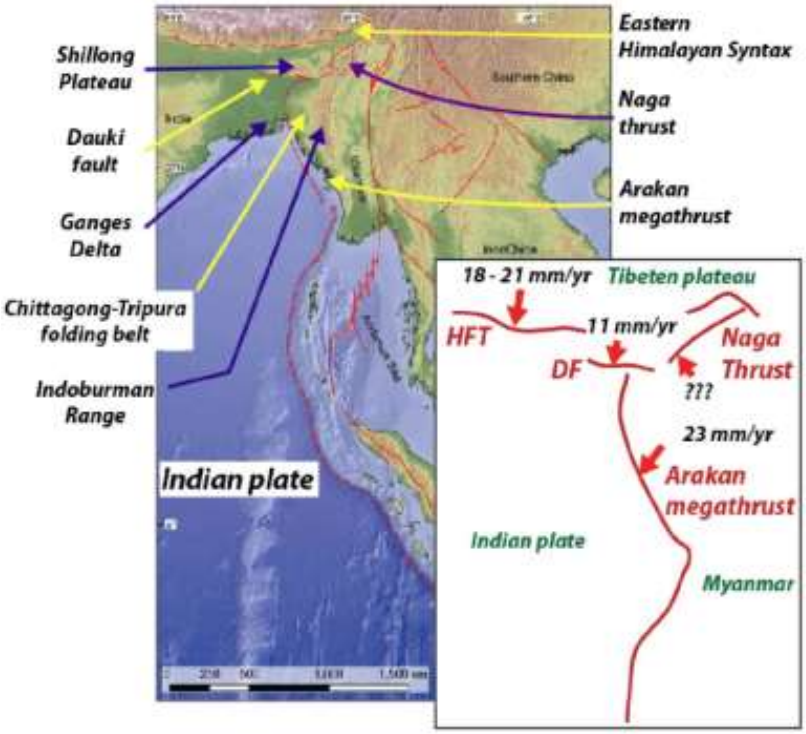


Figure 0.2: Major active tectonic elements of the region also include the Arakan megathrust, which at the latitudes of Bangladesh manifests as the Chittagong-Tripura fold belt and the underlying megathrust. Estimated current convergence rates of these major faults systems range from 11 to 23 mm/yr

Source: Wang et.al, 2013

1.2.1.2 Modeling of Earthquake Sources

To properly describe the complex earthquake sources in the study region, they are modeled as a mixture of background seismicity, sub-duction area sources, and crustal faults. These sources models are described in more detail below.

Background Seismicity Model

The background seismicity model represents random earthquakes in the whole study region except the sub-duction zones. The model accounts for all earthquakes in areas with no mapped seismic faults and for smaller earthquakes in areas with mapped faults.

In the conventional approach, the study region will be divided into several source zones, where different zones may have different rates of seismicity, but within each zone the rate of seismicity is assumed to be uniform throughout. This is to account for the spatial variation of seismicity rate in the study region. The intrinsic drawback of this conventional approach is that the seismic hazard assessment results can be significantly affected by the delineation of these zones, which could be heavily dependent on the subjective judgment of the hazard analyst.

In the USGS's approach, which is adopted in this study, it is not necessary to divide the study region into several source zones. One large zone may be used, but the rate of seismicity is assumed (or allowed) to vary from place-to-place within the zone. The rate of seismicity is determined by first overlaying a grid with a given spacing, in the current case 0.1^o in latitude and 0.1^o in longitude, approximately 10 km by 10 km onto the zone, and counting the number of earthquakes with magnitude greater than a reference value (M_{ref}) in each grid cell. The rate of seismicity is computed by dividing the number of earthquakes by the time period of earthquake data. The rate is then smoothed spatially by a Gaussian-function moving average and comparing with the observed seismicity. By this approach, the spatially varied seismicity can be modeled without being affected by the subjectivity of the hazard analyst.

In hazard calculations, earthquakes smaller than magnitude 6.0 are characterized as point sources at the centre of each grid cell, whereas earthquakes larger than magnitude 6.0 are assumed to be hypothetic infinite vertical or dipping faults centered on the source grid cell. Lengths of finite faults are determined during the Well and Copper Smith (1994) relations. Consecutively, the pre-calculated average source-to-site distance from virtual faults with strike directions uniformly distributed is employed (Petersen et al. 2008).

The whole study region is divided into three source zones: Back Ground Shallow (BGS), Back Ground Intermediate (BGI), Back Ground Deep (BGD) for background seismicity (see Figure 1.3, 1.4 and 1.5), active faults, and six source zones for sub-duction: SD-Bhutan, SD-Nepal, SD-Assam, SD-Arakan, SD-Ramree, and SD-Nega. Those zones with SD-X represent either sub-duction zone or continental collision, which will be described in detail in Section 'Subduction Zone Model' (page 9). The zone BGS is a shallow depth background seismicity zone. The BGI is designated for intermediate depth earthquakes (from 50 to 100 km depth), and the BGD is for deep earthquakes with hypocentral distance greater than 100 km.

We model the magnitude-dependent characteristic of the seismicity rate in each background seismicity zone by a truncated exponential model (Gutenberg-Richter model):

Log10 (N(MW)) = a – b MW -(1)

Where *N (MW)* is the annual occurrence rate of earthquakes with magnitude greater than or equal to *MW* and *a* and *b* are the Gutenberg-Richter model parameters. The parameter *b* is assumed to be uniform throughout the whole background region. Hence, we used complete earthquake data with magnitude greater than 4.0 to compute a single regional *b-value*. The obtained regional b-value is 0.90, and this value is used.

The *a*-value varies from place to place within each zone. It is computed by using a grid with spacing of 0.1° in latitude and longitude and is spatially smoothed using a two-dimensional Gaussian moving average operator with a correlation distance parameter C (Frankel, 1995). Earthquake data with *MW* > 4.0and C = 50 km are used. The correlation distance is chosen based on Frankel (1995) and it is comparable to earthquake location error. Note that at present there are no fixed rules or guidelines to determine an appropriate *C* value. If the value of *C* is too small, the resulting smoothed seismicity will be concentrated around the epicentres of past-recorded earthquakes. On the other hand, if the value of *C* is too large, the resulting smooth seismicity will be blurred and will not reflect the true spatial variation pattern of seismicity. The chosen *C* values are believed to be suitable as the computed smoothed rate 10^a values (presented in Figures 1.3, 1.5 and 1.7) are in agreement to observe spatial pattern of seismicity in Figures 1.4, 1.6 and 1.8.

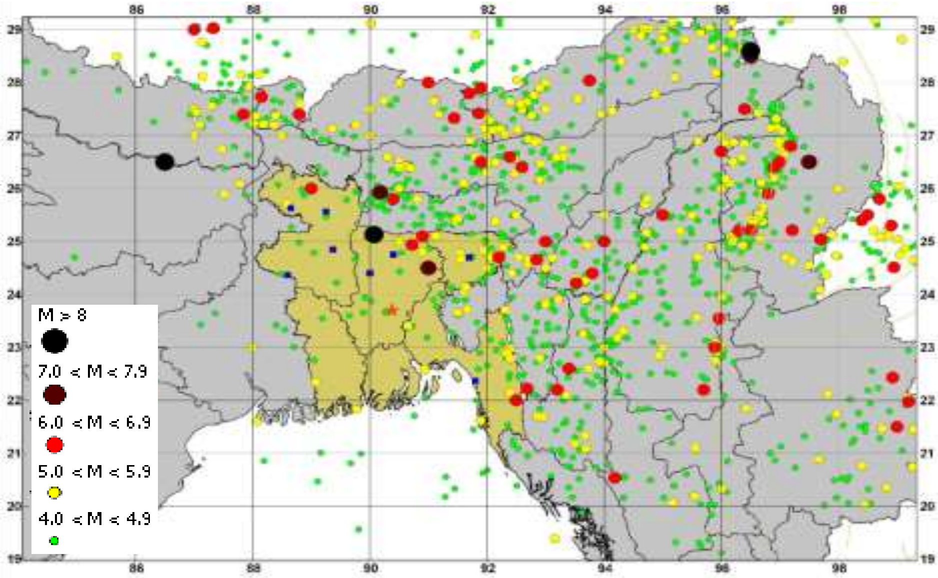


Figure 0.3: Bangladesh and its surrounding shallow seismicity (focal depth < 50 km) from 1897 to 2012

Source: CDMP-II, MoDMR, 2014

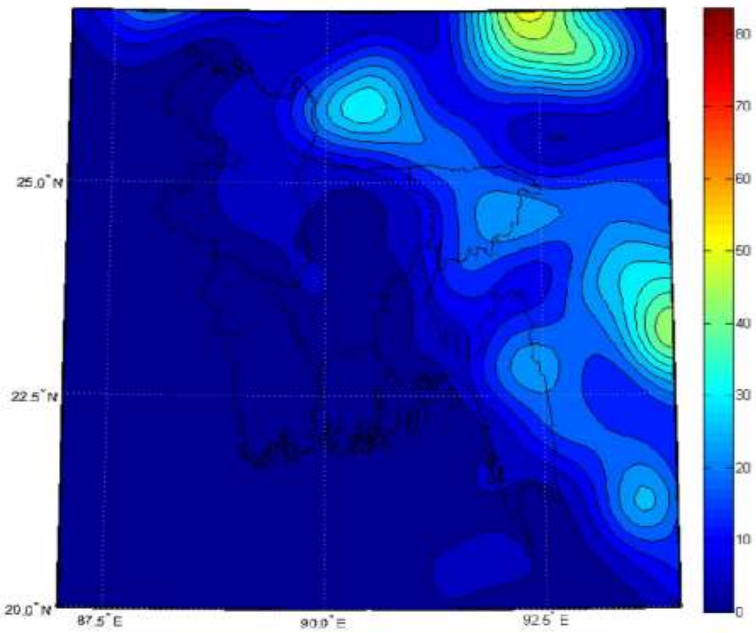


Figure 0.4: The smoothed activity rate 10^a value for Bangladesh

Source: CDMP-II, MoDMR, 2014

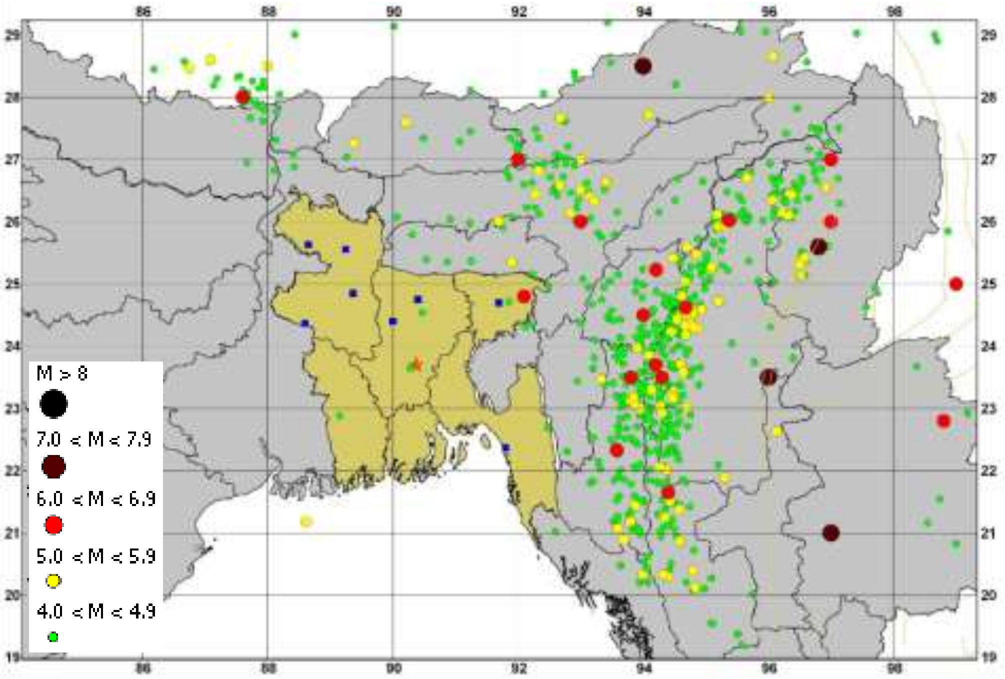


Figure 0.5: Bangladesh and its surrounding intermediate seismicity (50 km <focal depth <100 km) from1907 to 2012

Source: CDMP-II, MoDMR, 2014

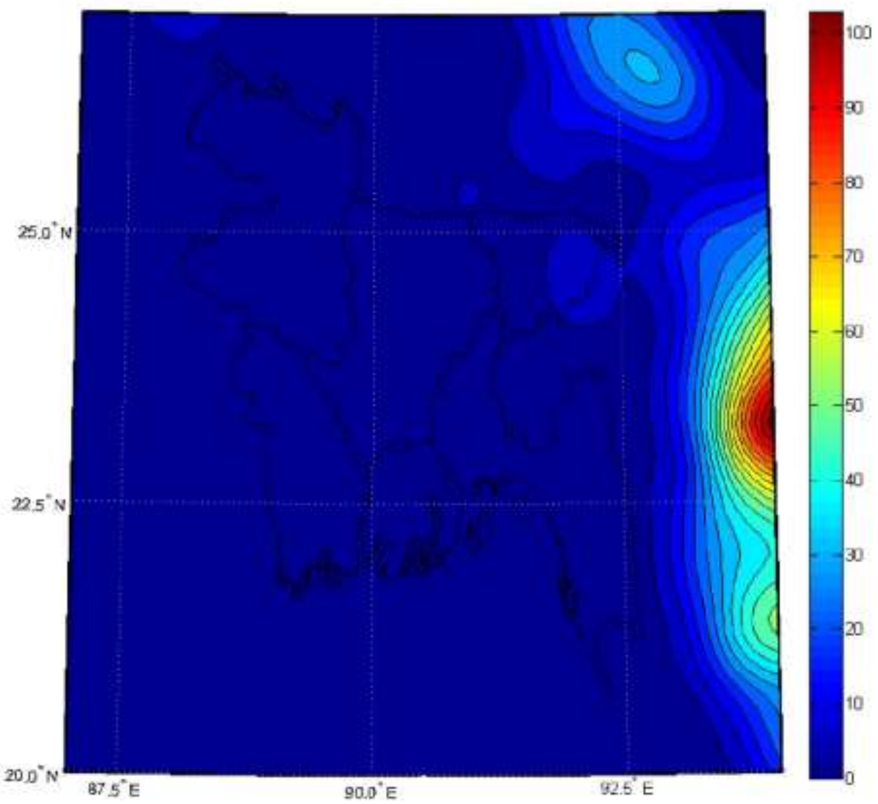


Figure 0.6: The smoothed activityrate10^{a} value for intermediate depth earthquakes

Source: CDMP-II, MoDMR, 2014

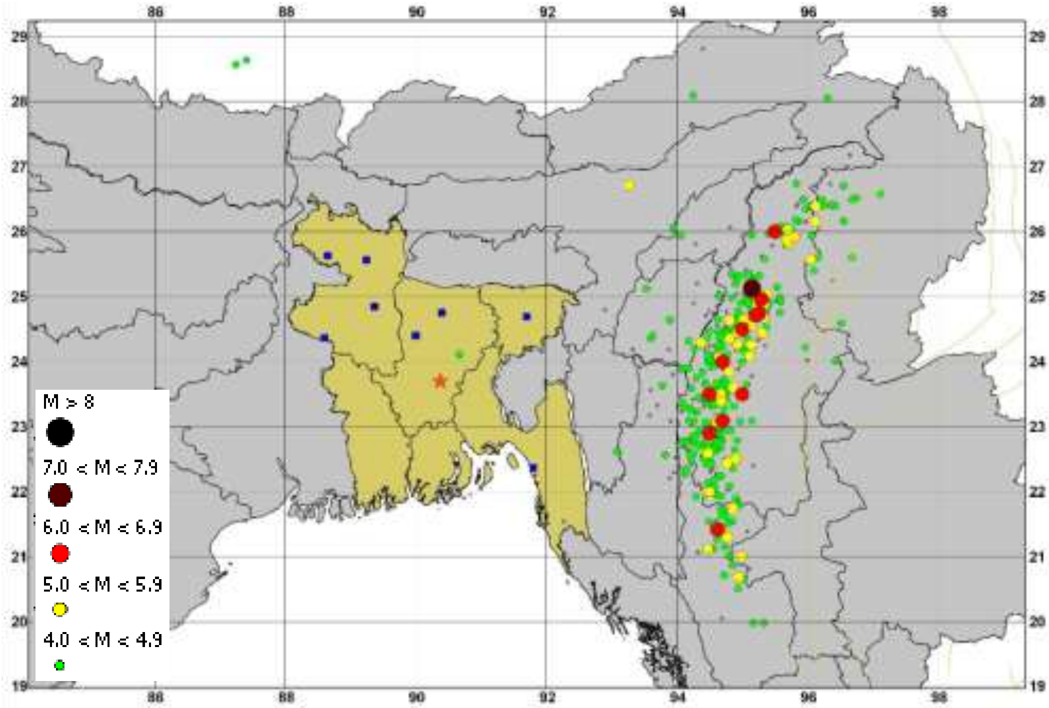


Figure 0.7: Bangladesh and its surrounding deep seismicity (focal depth>100km) from1907 to 2012

Source: CDMP-II, MoDMR, 2014

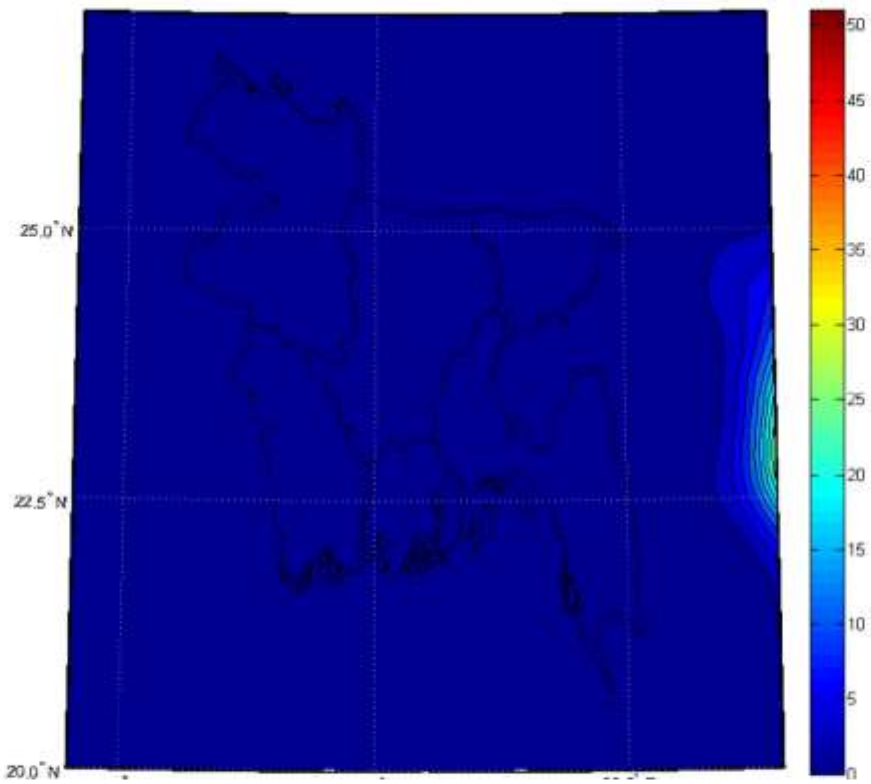


Figure 0.8: The smoothed activity rate10^a value for deep depth earthquakes

Source: CDMP-II, MoDMR, 2014

Sub-duction Zone Model

The mega thrust sub-duction zone have been identified and separated into six zones based on seismicity characteristics and tectonic settings. The geometry and recurrence times of large earthquakes associated with these active tectonic structures are largely based on paleoseismological study performed by Morino et al. (2011, 2013) and geodetic data, (Steckler, et al., 2008; Wang and Sieh, 2013). Each zone is modeled as a seismic area source with a uniform rate of seismicity (the conventional area source model), and the magnitude-frequency distributions is modeled by the characteristic model.

The maximum magnitude for zone SD-Nepal, Bhutan, Assam, Arakan (Chittagong), Arakan (Ramree) and Nega are set to be 8.4, 8.4, 8.4, 8.5, 8.4, and 8.0, respectively based on its tectonic settings and possible rupture area. The calculated recurrence intervals are shown in Table 1.1. The maximum magnitude for zone SD-Nepal and SD-Assam is set to 8.4 as the 1934 Bihar earthquake and the 1950 Assam earthquake have already demonstrated the capability of the zones to generate large mega thrust earthquakes. A sub-duction earthquake in each zone is assumed to be created by rupture along an inclined plane at the interface between two tectonic plates (interface earthquake). The fault plane ranges from 20 km depth at the top part of zone boundary down to 50 km depth at the bottom part of zone boundary. Moreover, more discussion regarding to Arakan mega thrust (Chittagong) section would be furthered addressed in the next section due to its proximate location to Dhaka as well as its potential capability to generate mega thrust earthquake that could have major impact toward seismic hazard for Bangladesh.

Table 0.1: Subduction zone model and their recurrence interval used in this study

Fault name	Length (km)	Dip angle	Locking depth (km)	Fault width (km)	Sliprate (mm/yr)	Mma	Average slip (m)	Recurrence interval (yr)	Date of last event
MainFrontal Thrust (SD- Nepal)	400	10	20	100	20	8.4	12	500	1934
MainFrontal Thrust (SD- Bhutan)	40	10	20	115	21	8.4	12	571	1100(?)
MainFrontal Thrust (SD- Assam)	400	10	20	150	20	8.4	12	500	1950
Arakanmegathrust (Rahkine section)	440	16	30	108	23	8.4	10	500	1762
ArakanMegathrust (Chittagong section) E	360	5	20	200	10	8.4	10	1,000	1548?
ArakanMegathrust (Chittagong section) M	360	5	20	200	7	8.4	10	1,500	1548?
ArakanMegathrust (Chittagong section) W	360	5	20	200	3	8.4	10	3,000	1548?
Naga thrust	360	23	20	50	5	8.0	2.7	540	?

Source: Morino et al. (2011, 2013); Steckler, et al., 2008; Wang and Sieh, 2013

Arakan Mega Thrust (Chittagong Section)

Based on Wang and Seih (2013), there are two reasons that the northern end of the Ramree patch near Chittagong. First, this is currently the farthest north for plausible evidence of mega thrust rupture in 1762 (Cummins, 2007). Second, it is in this region that the belt of upper-plate folds begins to widen substantially (Figure 3.36). Concomitant with this widening is an increase in the flatness of the mega thrust. Maurin and Rangin (2009) suggest that this Chittagong section of the mega thrust is nearly flat. Steckleret al. (2008) suggest it dips 5 to 7° eastward, based upon a structural analysis.

Westward-decreasing slip on this shallow-dipping section of the mega thrust/decollement is resulting in the construction of the Chittagong-Tripura fold belt, a broad swath of anticlinal ridges and synclinal troughs formed within the accreted Bengal Fan sedimentary sequence. These large but secondary structures arise from bends in the mega thrust and/or secondary thrust faults that bleed slip off of it.

Steckler et al. (2008) deduce a slip rate of 1 to 2 cm/yr on the megathrust, based upon a structural analysis of previously published data. Recent, unpublished geodetic data from GPS stations spanning Bangladesh show a contraction of about 8 mm/yr across the fold belt between 91.5 and 92.5°E (Figure 1.10). A simple elastic model in which the megathrust is locked from 92.5°E to the deformation front and is slipping farther east at 1 cm/yr fits these data (Figure 3.36). The locking depth of the mega thrust in this model is about 20 km, about 200 km east of the deformation front.

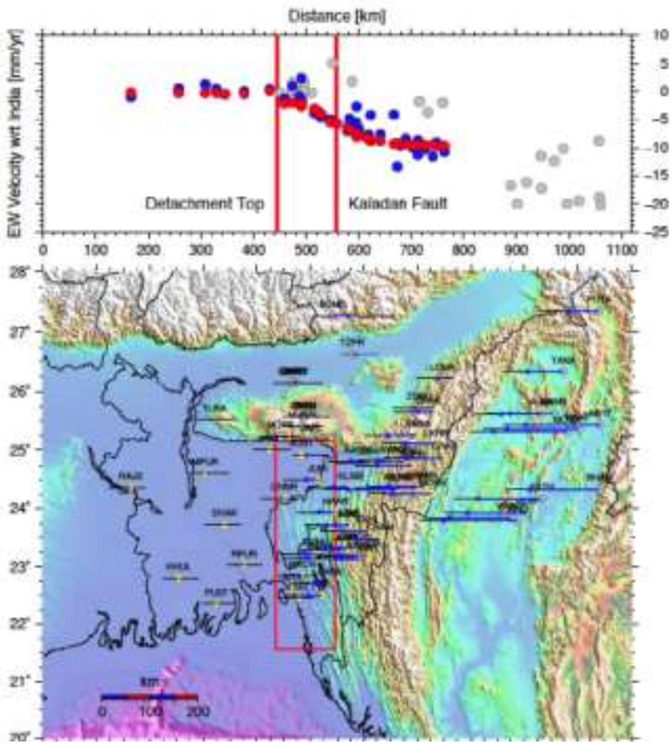


Figure 0.9: E-W velocities of GPS stations in the Indo-Burman ranges and Chittagong-Tripura Fold Belt and a model fit. A. Map of measured velocities.

Source: Wang and Sieh, 2013

Data courtesy of H. Akter (personal communication), Dhaka University. Measured E-W velocities (blue) compared to modeled velocities (red). In both panels, the red lines demarcate the limits of a locked rectangular patch on the mega thrust. Slip at 10mm/yr occurs down dip (east) of the locked patch. Model courtesy of Lujia Feng, Earth Observatory of Singapore.

In addition, unpublished GPS data in Bangladesh also further indicates that the shortening rate across Arakan Mega thrust (Chittagong section) is increasing from west to east. From the western margin, the shortening rate is increasing from 0.2 cm/year, 0.5 cm/year, and 1 cm/year. This could be interpreted that the Arakan Mega thrust (Chittagong section) should have different recurrence intervals from west to east. The eastern segment may have long recurrence interval of a thousand years based on an elastic model, (Wang and Sieh, 2013), while the middle and west sections should have longer recurrence interval of 1,500 and 3,000 years, respectively. The location of main frontal thrust for mega thrust section with 7 mm/year at 90.5^{o} longitude since it is previously identified as a main frontal thrust in Morino et al. (2013) report. Moreover, this mega thrust section with 7 mm/year is located around Comilla Hill where Morino et al. (2013) reported paleo liquefaction evidence.

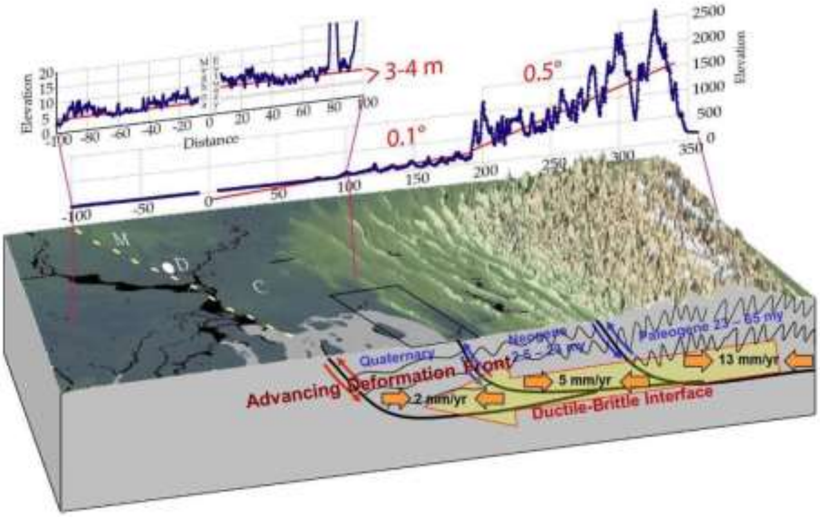


Figure 0.10: E-W shortening rate based on unpublished GPS stations in the Indo-Burman ranges and Chittagong-Tripura Fold Belt.

Source: Akter, 2010

Crustal Fault Model

The information about crustal faults in and near Bangladesh is mainly obtained from recent paleoseismic investigations carried out by Morino et al. (2011; 2013). The investigations were conducted using a mix of remote sensing imagery, aerial photographic interpretation and field investigation. The investigation concentrated on the geomorphic expression of faulting, and the comparison of these features with those observed along other active faults around the world. Their important properties and parameters are shown in Table 1.2.

Table 0.2: Crustal fault source model and their recurrence interval used in this study

Fault name	Length (km)	Dip angle	Locking depth (km)	Fault width (km)	Slip rate (mm/yr)	Mma	Average slip (m)	Recurrence interval (yr)	Date of last event
Dauki fault	270	45	35	50	11	7.9	2.5	250	1897

Source: Morino et al. (2011; 2013)

The Dauki Fault is a major is a north-dipping reverse fault, passes on the southern margin of the Shillong Plateau (Fig. 1.2). The Shillong Plateau is composed of bedrocks of the Indian shield, which was uplifted by the activity of the Dauki fault, approximately 2000 m high. The Dauki fault is thought to be an active fault related to the collision boundary, since its strike is parallel to the Himalayan Strike Slip (HSS), while it is an intra-plate active fault with in the Indian plate. The available assigned slip rate of 11 mm/year is based on geodetic data suggested by GPS studies spanning the HFT and the Dauki fault, which is in agreement with an elastic deformation model with slip rates of 21 and 11 mm/year freely slipping down dip extensions of both faults fits these data well (Banerjee et al. 2008). In addition, the occurrence rate of large magnitude earthquakes on crustal faults is determined from long-term slip rates and the characteristic earthquake magnitude (MC). MC is estimated from expected rupture length, which may be limited by fault segmentation, by using the relation proposed by Wells and Coppersmith (1994).

The magnitude-dependent characteristic of the seismicity rate of these crustal faults has been employed. In the characteristic earthquake model, three characteristic earthquake magnitudes are also considered: MC − 0.2, MC, and MC + 0.2. The probabilistic weights of 0.2, 0.6, and 0.2 are assigned to these cases, respectively. In each case, the earthquake occurrence rate is computed from the characteristic magnitude and the fault slip rate (to match with the seismic moment rate of the fault). The recurrence interval for the characteristic model is determined from:

Recurrence Interval = $\mu\bar{u}LW/M_{0C}$

Where μ is shear modulus, 3.0×1011 dyne/cm2, L is rupture length, and W is rupture width, ū is the fault slip rate, M0C is the characteristic earthquake moment, which is calculated from:

$\log (M_{0C}) = 1.5M_C + 16.05$

and the magnitude is assumed to be normally distributed around the characteristic value with a standard deviation of 0.12.

Ground Motion Prediction Equations (GMPES)

The ground motion parameters, such as PGA and spectral acceleration (SA), at a given site can be estimated from the earthquake magnitude, source-to-site distance, and local site condition by appropriate GMPEs. Traditionally a ground-motion model for a specific region is empirically developed from statistical regression analyses, using available earthquake ground motion records (e.g. Douglas, 2003). For the study region, however, a very limited number of strong-motion records are available. One solution to this data limitation is to assume that some existing GMPEs developed for other regions with similar seismotectonic characteristics can adequately represent ground-motion scaling in this region.

In this study, three Next Generation Attenuation (NGA) models developed for shallow crustal earthquakes in the Western United States and similar active tectonic regions are applied for back ground earthquakes in BGS and for earthquakes from crustal faults in the study region. These NGA models were developed by Boore and Atkinson (2008), Campbell and Bozorgnia (2008), and Chiou and Youngs (2008) during the NGA project. Examples of ground motion attenuation curves computed by these NGA models for MW = 5.0, 6.0 and 7.0 are shown in Figure 1.11. Sabetta et al. (2005) suggested that the selection of appropriate GMPEs in an analysis has a greater impact than the expert judgment applied in assigning relative weights; therefore, equal probabilities (i.e. 1/3) have been assigned to these three models in the logic trees analysis.

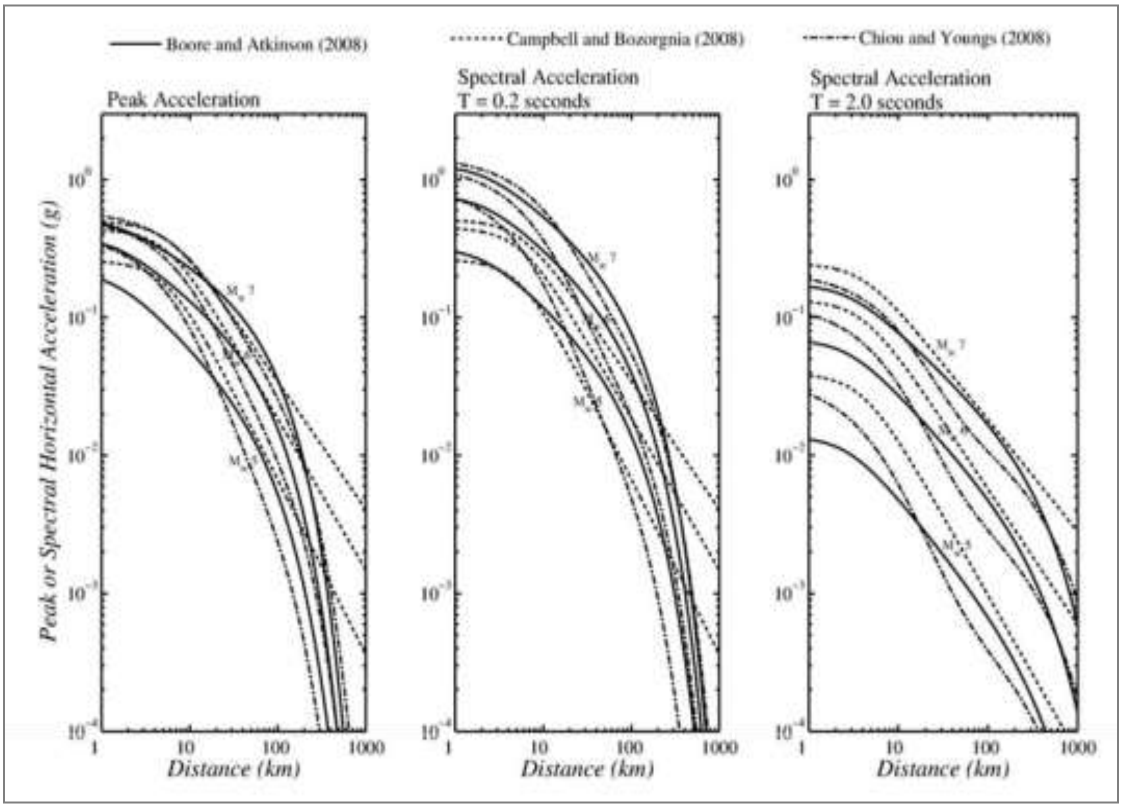


Figure 0.11: Attenuation curves for PGA and SA at 0.2 and 2sec (5% damping) computed by selected ground motion prediction equations for shallow crustal earthquakes (horizontal motion)

Source: Boore and Atkinson, 2008; Campbell and Bozorgnia, 2008; Chiou and Youngs, 2008

For sub-duction zone earthquakes, we adopt the three sub-duction zone ground-motion models developed by Youngs et al. (1997), Atkinson and Boore (2003; 2008) (both of which are based on global data), and Zhao et al. (2006) (mainly based on data from Japan).

Examples of ground motion attenuation curves computed by these selected sub-duction zone ground-motion models for MW = 6.5, 7.5 and 8.5 are shown in Figure 1.12.

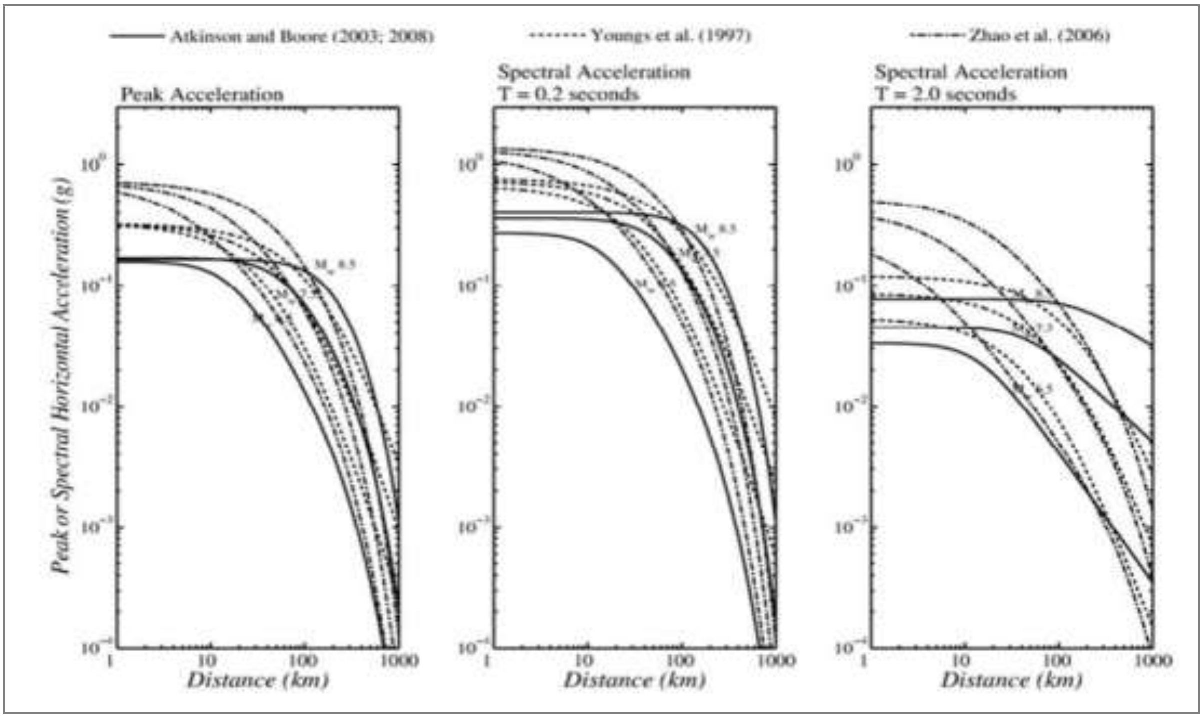


Figure 0.12: Attenuation curves for PGA and SA at 0.2 and 2 sec (5 percent damping) computed by selected ground motion prediction equations for sub-duction zone earthquakes (horizontal motion).

Source: Young et al., 1997; Atkinson and Boore, 2003

Probabilistic weights assigned to these models are 0.25, 0.25, and 0.50, respectively. To calculate ground motion for intermediate- and deep- depth earthquakes, Young et al. (1997) and Atkinson and Boore (2003) equations have been considered with equal weights.

The effects of all earthquakes of different magnitudes, occurring at different locations in different seismic sources at different probabilities of occurrence are integrated into hazard curves. Each hazard curve shows the probability of exceeding different PGA levels at the site during a specified period of time. From the obtained hazard curves, uniform hazard response spectra for 50-, 100-, 200-, 500- and 1000-year return periods at the sites of investigation are derived and interpolated to develop earthquake hazard maps representing spatial variation of PGA in Bangladesh.

1.2.2 Analysis of Hazard Assessment

Among 50-, 100-, 200-, 500- and 1000-year return period earthquake hazard maps, detailed analysis of a 50-year return period earthquake hazard map was carried out and given here. The earthquake hazard map is analyzed for distribution among various divisions of Bangladesh. The distribution is shown in Table 1.3.

Table 0.3: Percentage of area distribution in each earthquake intensity category range in each division

Division	Earthquake intensity - PGA (g) range vs Percentage of Area		
	< 0.05	0.05 - 0.15	0.15 - 0.35
Barisal	-	100.00	-
Chittagong	-	13.10	86.90
Dhaka	-	66.69	33.31
Khulna	-	100.00	-
Mymensingh	-	56.18	43.82
Rajshahi	0.03	54.86	45.11
Rangpur	-	16.38	83.62
Sylhet	-	-	100.00

In analyzing Table 1.3, entire Sylhet division is in the Moderate earthquake intensity (PGA range of 0.15 – 0.35) along with 86.90 % of Chittagong division and 83.62 % of Rangpur. About 43.82 % of Mymensingh division and 33.31 % of Dhaka division is also in Moderate earthquake intensity zone, which is represented by 28 districts in all. For these 28 districts, areal extent and percentage in each earthquake intensity zone is given Table 1.4. Entire Khulna and Barisal divisions are in Low earthquake intensity (PGA range 0.05 – 0.15) zone and about 66.69 % of area in Dhaka division and 56.18 % of Mymensingh division is in low earthquake intensity.

Table 0.4: Areal extent and percentage of moderate and above earthquake intensity category in most affected districts

Division Name	District Name	Earthquake intensity - PGA (g) range					
		< 0.05		0.05 - 0.15		0.15 - 0.35	
		Area (km2)	Percentage	Area (km2)	Percentage	Area (km2)	Percentage
Barisal	Barguna	-	-	1,831.31	100.00	-	-
	Barisal	-	-	2,784.52	100.00	-	-
	Bhola	-	-	3,403.48	100.00	-	-
	Jhalokati	-	-	706.76	100.00	-	-
	Patuakhali	-	-	3,221.31	100.00	-	-
	Pirojpur	-	-	1,277.80	100.00	-	-
Chittagong	Bandarban	-	-	-	-	4,479.01	100.00
	Brahmanbaria	-	-	-	-	1,881.20	100.00
	Chandpur	-	-	1,220.44	74.18	424.88	25.82
	Chittagong	-	-	-	-	5,282.92	100.00
	Comilla	-	-	257.37	8.18	2,888.93	91.82
	Cox's Bazar	-	-	-	-	2,491.85	100.00
	Feni	-	-	-	-	990.36	100.00
	Khagrachhari	-	-	-	-	2,749.16	100.00
	Lakshmipur	-	-	1,338.10	92.90	102.29	7.10
	Noakhali	-	-	1,572.86	42.67	2,113.01	57.33

Division Name	District Name	Earthquake intensity - PGA (g) range					
		< 0.05		0.05 - 0.15		0.15 - 0.35	
		Area (km2)	Percentage	Area (km2)	Percentage	Area (km2)	Percentage
	Rangamati	-	-	-	-	6,116.11	100.00
Dhaka	Dhaka	-	-	1,463.60	100.00	-	-
	Faridpur	-	-	2,052.86	100.00	-	-
	Gazipur	-	-	847.42	46.91	958.94	53.09
	Gopalganj	-	-	1,468.74	100.00	-	-
	Kishoreganj	-	-	-	-	2,688.59	100.00
	Madaripur	-	-	1,125.69	100.00	-	-
	Manikganj	-	-	1,383.66	100.00	-	-
	Munshiganj	-	-	1,004.29	100.00	-	-
	Narayanganj	-	-	635.29	92.83	49.08	7.17
	Narsingdi	-	-	30.60	2.66	1,119.54	97.34
	Rajbari	-	-	1,092.28	100.00	-	-
	Shariatpur	-	-	1,174.05	100.00	-	-
	Tangail	-	-	1,399.13	40.98	2,015.22	59.02
Mymensingh	Jamalpur	-	-	-	-	2,115.16	100.00
	Mymensingh	-	-	-	-	4,394.57	100.00
	Netrakona	-	-	-	-	2,794.28	100.00
	Sherpur	-	-	-	-	1,364.67	100.00
Khulna	Bagerhat	-	-	3,959.11	100.00	-	-
	Chuadanga	-	-	1,174.10	100.00	-	-
	Jessore	-	-	2,606.94	100.00	-	-
	Jhenaidah	-	-	1,964.77	100.00	-	-
	Khulna	-	-	4,394.45	100.00	-	-
	Kushtia	-	-	1,608.80	100.00	-	-
	Magura	-	-	1,039.10	100.00	-	-
	Meherpur	-	-	751.62	100.00	-	-
	Narail	-	-	967.99	100.00	-	-
	Satkhira	-	-	3,817.29	100.00	-	-
Rajshahi	Bogra	-	-	-	-	2,898.68	100.00
	Chapai Nawabganj	5.98	0.35	1,696.57	99.65	-	-
	Joypurhat	-	-	-	-	1,012.41	100.00
	Naogaon	-	-	2,007.81	58.44	1,427.84	41.56
	Natore	-	-	987.09	51.95	913.10	48.05
	Pabna	-	-	2,278.91	95.91	97.22	4.09
	Rajshahi	-	-	2,339.97	96.48	85.40	3.52
	Sirajganj	-	-	647.68	26.96	1,754.37	73.04
Rangpur	Dinajpur	-	-	1,154.38	33.52	2,289.92	66.48
	Gaibandha	-	-	-	-	2,114.77	100.00
	Kurigram	-	-	-	-	2,245.04	100.00
	Lalmonirhat	-	-	-	-	1,247.37	100.00

Division Name	District Name	Earthquake intensity - PGA (g) range					
		< 0.05		0.05 - 0.15		0.15 - 0.35	
		Area (km2)	Percentage	Area (km2)	Percentage	Area (km2)	Percentage
	Nilphamari	-	-	-	-	1,546.59	100.00
	Panchagarh	-	-	-	-	1,404.62	100.00
	Rangpur	-	-	-	-	2,400.56	100.00
	Thakurgaon	-	-	1,487.15	83.47	294.59	16.53
Sylhet	Habiganj	-	-	-	-	2,636.59	100.00
	Maulvibazar	-	-	-	-	2,799.38	100.00
	Sunamganj	-	-	-	-	3,747.18	100.00
	Sylhet	-	-	-	-	3,452.07	100.00

Among the 28 districts, six districts (Maulvibazar, Sunamganj and Sylhet in Sylhet division, Khagrachari and Rangamati in Chittagong division and Kurigram in Rangpur division) and two districts (Habiganj in Sylhet division and Netrakona in Mymensingh division) almost completely exist in the very high earthquake hazard category.

1.2.3 Map Content

Based on PGA variation, range of PGA values are used to derive hazard category. Table 1.5 shows the hazard zones and colors used in the hazard maps.

Table 0.5: Earthquake hazard zones based on PGA range

Range of PGA values	Earthquake hazard category	Symbology used in maps
< 0.05	Very Low	
0.05 – 0.15	Low	
0.15 – 0.35	Moderate	
0.35 – 0.5	High	
> 0.5	Very High	

As explained earlier, earthquake hazard assessment results for Bangladesh are presented in terms of: PGA at 50-, 100-, 200-, 500- and 1000-year return periods.

All results presented in maps are developed for bedrock site condition. In general, at short return period, for instance 50 and 100 years, the PGA hazard map observed seismicity in and around Bangladesh controls the hazard for most considered structural periods. However, for long return periods, such as 500 and 1000 years, the seismic hazard of all structural period is controlled by major tectonic structures, and these results confirm the importance of further study of active tectonic structures in Bangladesh. For the 200-year return period, the PGA hazard map is fairly well correlated with the seismicity near Dauki fault. Ground motion across Bangladesh represented by PGA is in the range of 0.1–0.45 g, corresponding to the 200-year return period and in the range of 0.1–0.9 g, corresponding to the 1000-year return period. The effect of the high-slip-rate of Dauki fault could be observed as the largest seismic hazard zone in Bangladesh.

The peak ground acceleration (PGA) map representing the intensity of earthquake for 50-, 100-, 200-, 500- and 1000-year return periods are shown in Figures 1.13, 1.14, 1.15, 1.16 and 1.17 respectively.

Figure 0.13: PGA corresponding to 50-year return period earthquake

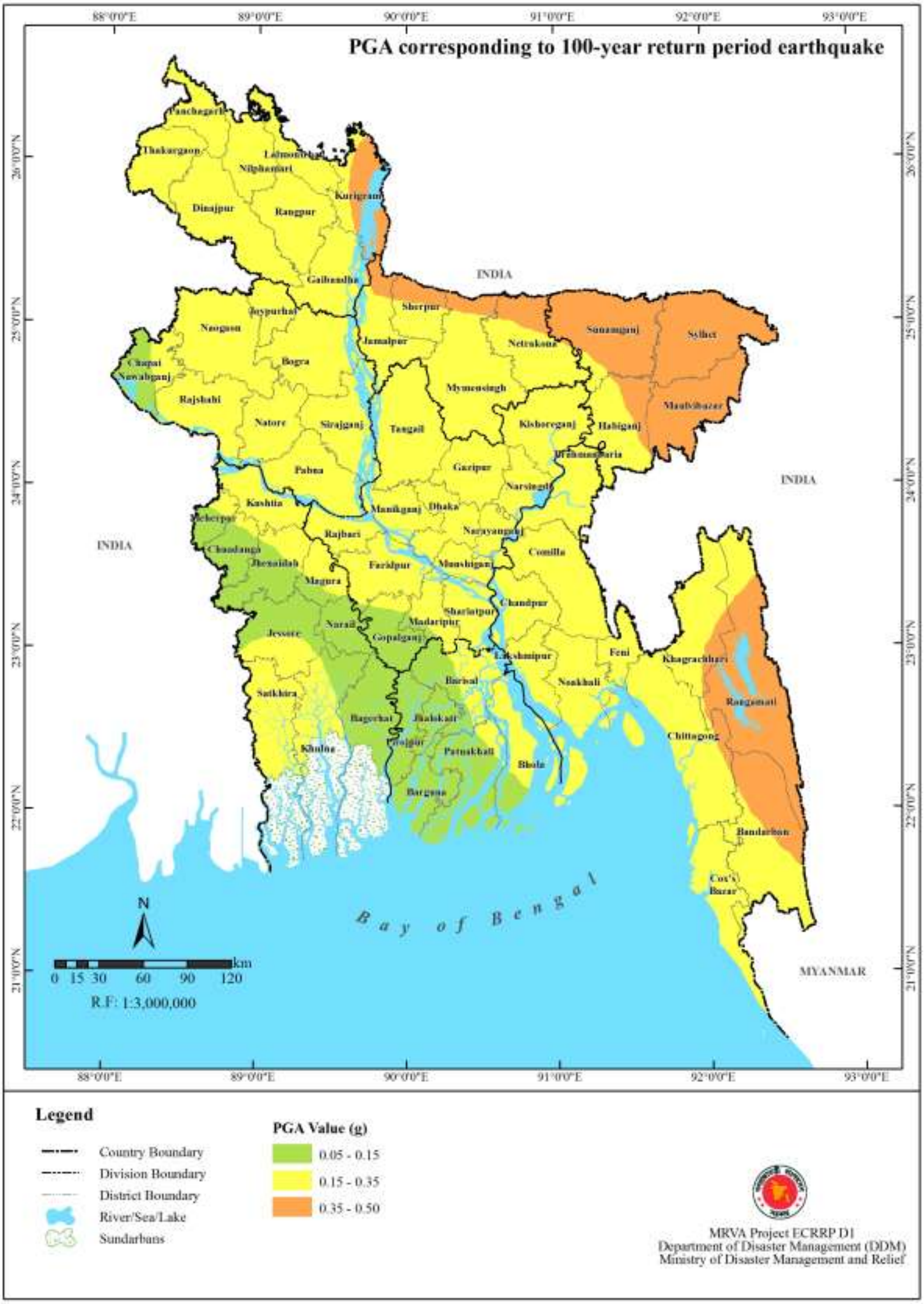


Figure 0.14: PGA corresponding to 100-year return period earthquake

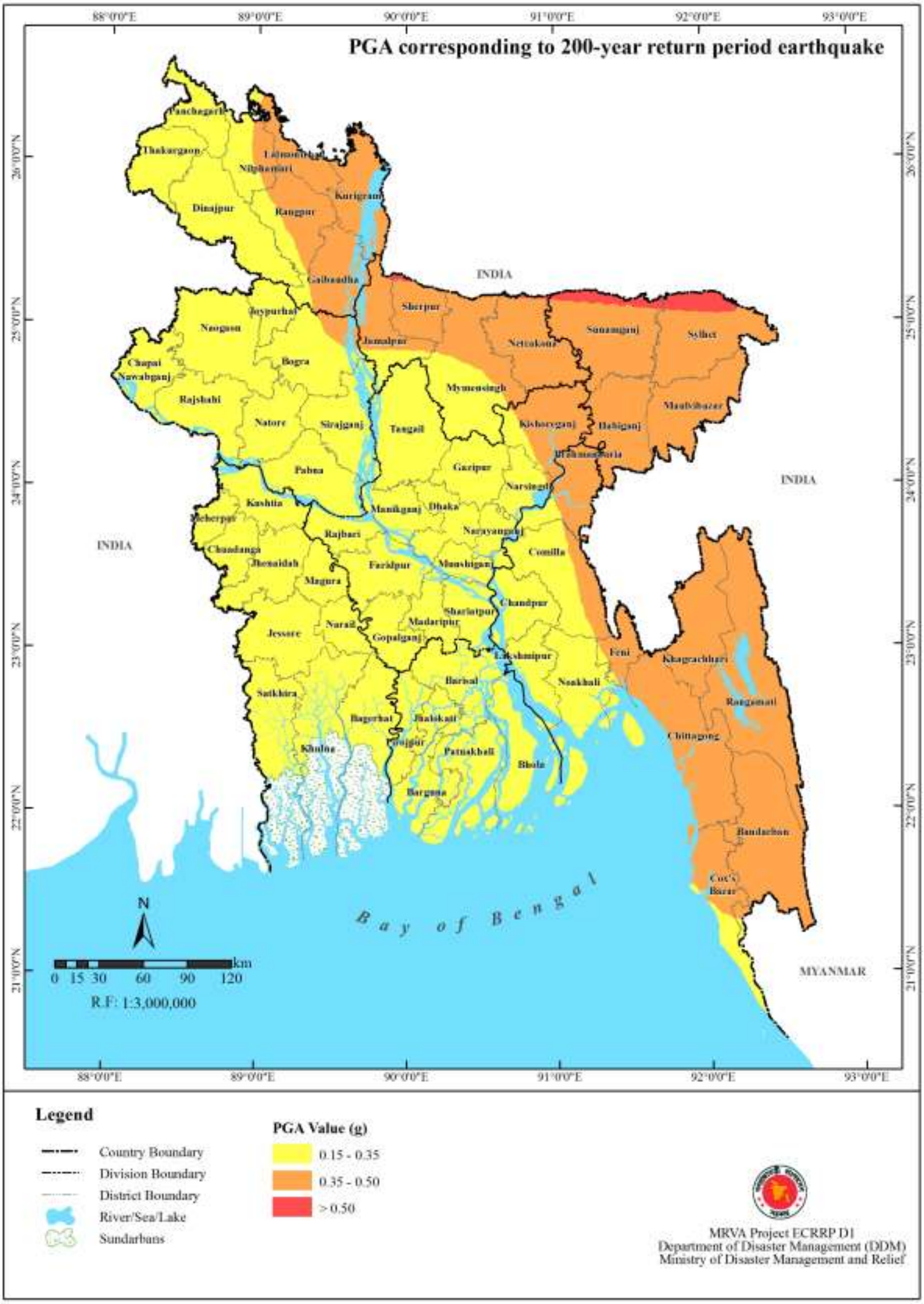


Figure 0.15: PGA corresponding to 200-year return period earthquake

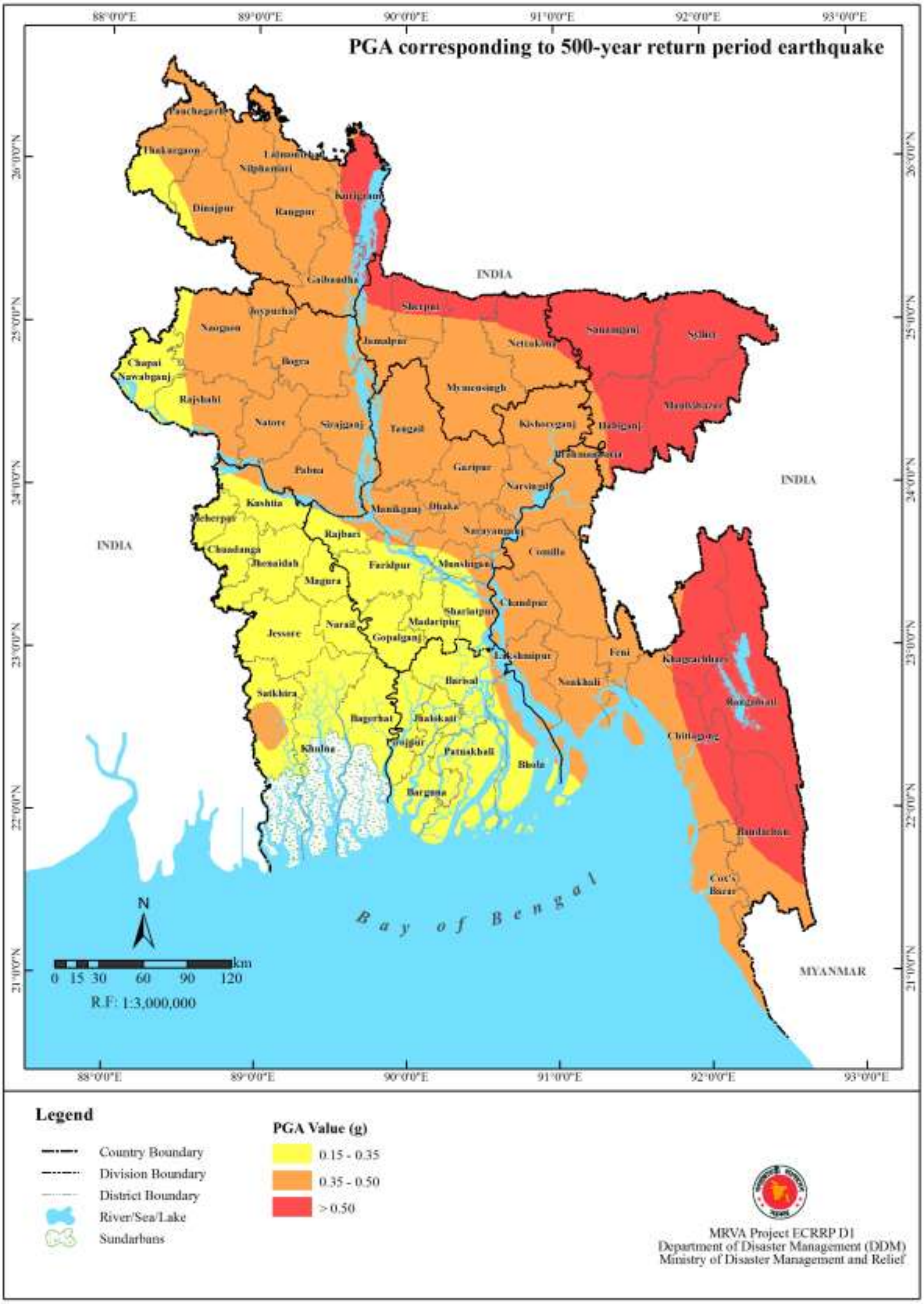


Figure 0.16: PGA corresponding to 500-year return period earthquake

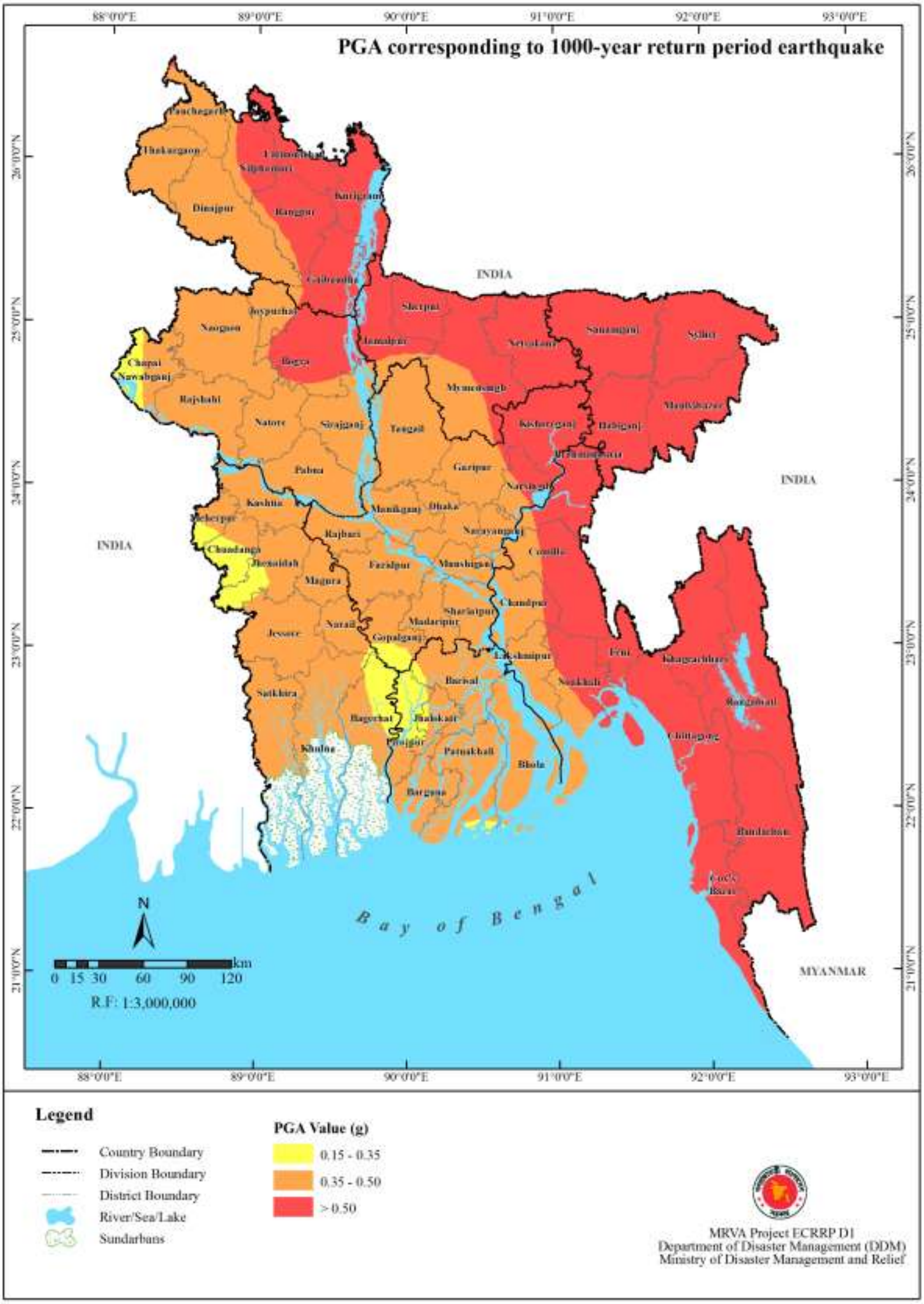


Figure 0.17: PGA corresponding to 1000-year return period earthquake

1.2.4 Application of Maps

Earthquake hazard maps are developed on a national scale for Bangladesh. Earthquake-prone areas have been delineated at the district level. These hazard maps are developed for several purposes, including the following:

- Earthquake hazard maps will be helpful for physical and infrastructural development. The maps will help policymakers and decision makers understand the severity of earthquake hazards and take necessary action to sustain the development through introducing necessary risk reduction measures in most possible areas.
- Most important sectors like housing, critical facilities and infrastructure need special attention for earthquake safety. The earthquake category zones will provide understanding about expected performance of structures during earthquakes and necessary measures to protect the structures.
- The zones will further help the local urban government to introduce and enforce building byelaws and building codes to protect the urban infrastructure.
- The maps will help national and international NGOs to prioritize the disaster risk reduction strategies.

1.2.5 Special Remarks

The earthquake hazard maps have been developed using very detailed geological investigations at the country level using almost all possible sources of earthquake data. The objective of using a more precise PGA value map instead of a MMI scale map is to create understanding among seismologists, geologists and civil engineers along with policy makers and decision makers to understand the distribution of the severity of earthquake risk in the country. Though PGA maps are not often used by other sectoral development and planning professionals since it consists of very precise information, it can be widely referred to and used by a large section of society.

1.2.6 Recommendations

The earthquake monitoring network is established by the Bangladesh Meteorological Department (BMD), which monitors seismic activities, compiles the report and provides necessary inputs in the country.

1.3 Tsunami

The Bangladesh coastline is about 710 kilometers long, comprising of 19 districts and 147 upazilas (CZPo, 2005). The total coastal zone covers an area of 47,211 km^2, which is about 32 percent of the total country (Islam, 2004). A total of 48 out of 147 upazilas are directly exposed to the sea, hence termed as the exposed coast, while the remaining 99 upazilas are classified as interior coast (Figure 1.18). The coastal region is low-lying, with 62 percent of the land has an elevation of up to 3 m, and 86 percent has up to 5 m from mean sea level. This enormous coastal area is home to about 36.8 million people, which is about 28 percent of the total population of Bangladesh with a density of 743 people per square kilometer (Coastal Zone Policy, 2005). The population is expected to increase to 43.9 million in 2015 and to 60.8 million by 2050 (PDO-ICZM, 2005).

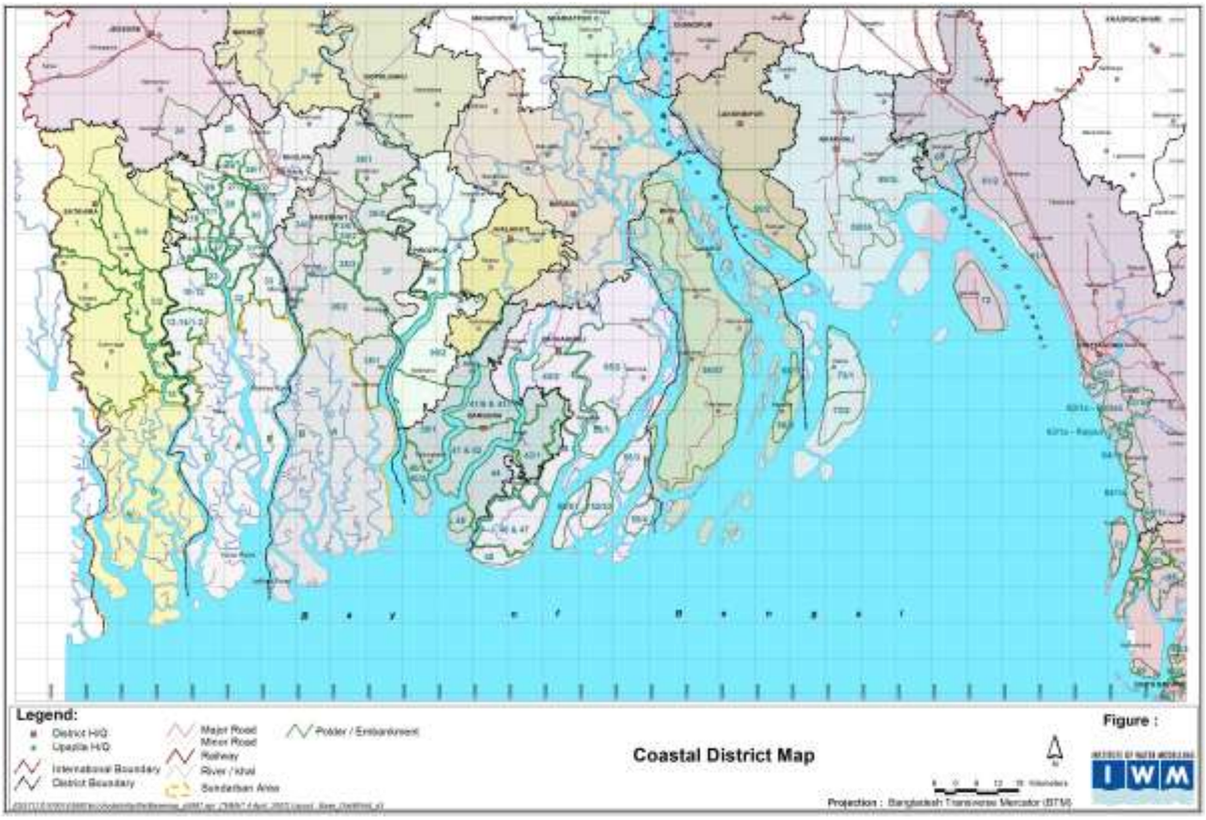


Figure 0.18: Coastal District Map of Bangladesh

Source: IWM, 2007

Geologically, Bangladesh is situated in the active plate collision zone and consequently endangered due to large magnitude of earthquakes occurring in the surrounding region. According to Cummins (2007), the tectonic environment at the Bay of Bengal region has similarities to other subduction zones that has experienced mega thrust earthquakes; stress and crustal strain observation indicates that the seismic zone is locked. The peril of generating tsunami along the coasts of Myanmar and Bangladesh is high due to the presence of a subduction zone, where one part of the Earth's crust is slowly driving under another. This active tectonic zone is situated in between the Indian plate and Myanmar plate that stretches up to Sumatra via Andaman-Nicobar zone of severe seismicity. The Sitakundu-Teknaf fault that runs along the Chittagong-Cox's Bazar coastline recommends a seismic gap that is alarming for Bangladesh's coast to tsunami (Sarker, 2008). The vicious "locked-thrust" fault, the kind that unleashes tsunamis, runs parallel to the shore in the similar fashion to the Sumatra fault, which caused the devastating tsunami on 26 December, 2004. The zone was locked for about 250 years when a massive earthquake hit the region on 2 April, 1762, which also caused a tsunami. The 200 Km long continental shelf is also said to be susceptible to earthquakes and landslides, and its margins are extremely vulnerable to local tsunamis.

The lack of preparedness and appropriate warning system for tsunamis has already placed this huge population in a vulnerable condition. The absence of any structural or non-structural measures to withstand tsunamis provides an additional risk. Bangladesh was less affected by the Indian Ocean tsunami on 26 December, 2004, but it has raised a question that whether and to what extent the country's coastal population is in potential threat due to tsunami.

An attempt has been made in this study to model the tsunamigenic conditions and the possible hazard maps due to tsunami, which have been generated for 50, 100, 200, 500 and 1000 years.

1.3.1 Data Used

The data required for the tsunami hazard assessment include bathymetry and topography of the coastal region of Bangladesh as well as fault plane parameters corresponding to tsunamigenic seismic scenarios in the subduction zones concerned. Moreover, field measurements of water levels due to pat tsunami events, for example those due to the tsunami in December 2004, are also required for model validation. Table 1.6 summarizes the data requirements, possible sources and whether or not such data were available for the present study.

Table 0.6: List of data requirements and availability for the tsunami hazard assessment

Type of Data	Source	Spatial Resolution	Availability for the Project
Bathymetric Data			
Entire Indian Ocean Basin	GEBCO	30 arc-seconds	Available
Seaboard off Bangladesh (Northern part of Bay of Bengal)	Navigation charts	1:150,000 or 1:300,000	Not Available
Local bathymetry at some near shore locations (if available)	Hydrographic Dept. of Bangladesh Navy	Varying	Not Available
Elevation data			
Coastal zone of Bangladesh			
LIDAR		Horizontal < 1 m Vertical < 0.3 m	Not Available
Land based surveys	Survey of Bangladesh	1:1000, 1:5000, 1:10,000 (at least 1 m contour interval)	Spot heights available
Coastal DEM	IWM, Bangladesh	Horizontal = 50 m;	Spot heights available

ASTER (or SRTM)	JPL, Caltec	Horizontal = 30 m; Vertical resolution not known	Available
Miscellaneous base data			
Administrative boundaries in vector format	Survey of Bangladesh	1:10,000 or better	Available; original resolution not known
Vector data depicting land use, drainage network, road network, etc.	-ditto-	-ditto-	-ditto-
Seismic data			
Fault parameters of seismic events	Scientific Publications	Varying	Available
Data on 2004 tsunami impact			
Tsunami heights	Scientific Publications	Varying	Limited availability for the coast of Bangladesh
Extent of inundation	Scientific Publications	-ditto-	

1.3.2 Methodology

A flow chart of the methodology that was adopted for mathematical modeling and mapping is given in Figure 1.19. In the following, tsunamigenic sub-duction zones applicable to the present study are identified and their seismic history briefly discussed prior to setting out the methodology to be adopted in assessing the tsunami hazard to Bangladesh.

1.3.2.1 Sub-duction zones

There are two major sub-duction zones with tsunami genic seismic potential in the Indian Ocean Basin, namely, a portion of the Sunda Arc stretching south from Bangladesh down to Java (Segment AE in Figure 1.19), and the Makran Subduction Zone (Segment FG) off the coastline of Pakistan and Iran in the Arabian Sea (Okal and Synolakis, 2008; Jaiswal et al., 2008). The western flank of the Sunda Arc may be further divided into four zones as in Figure 1.19: (a) Andaman-Myanmar (Arakan) (Segment AB); (b) Andaman-Northern Sumatra (Segment BC); (c) Southern Sumatra (Segment CD); and (d) Java (Segment DE).

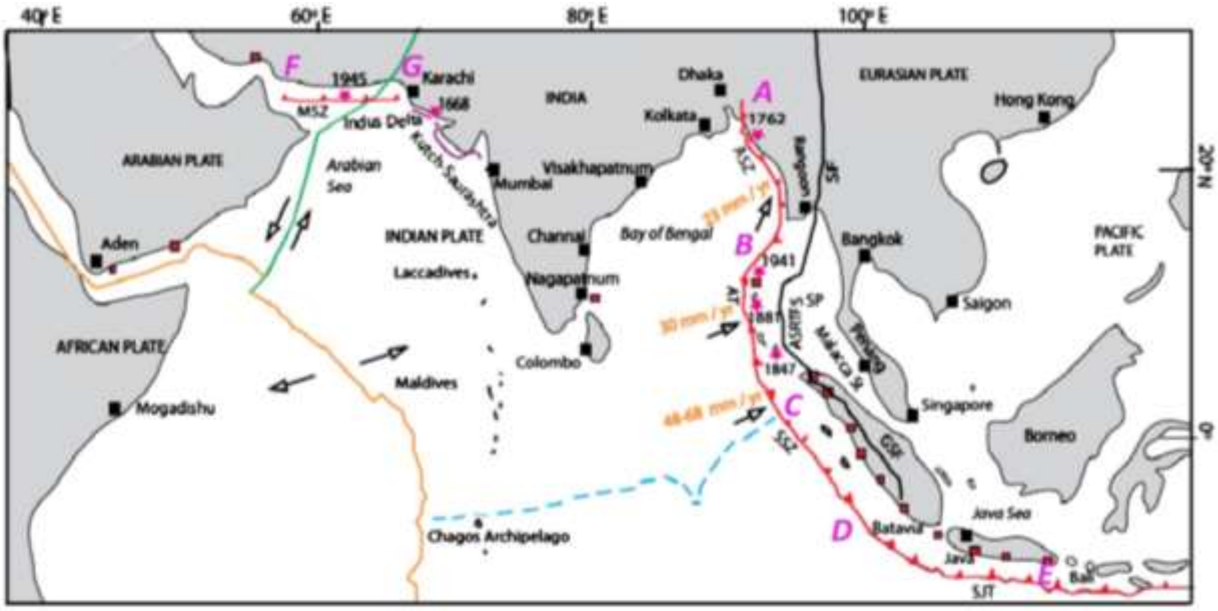


Figure 0.19: Sub-duction zones in the Indian Ocean Basin

Source: modified after Alam et al., 2012

However, tsunami events originating in that part of the Sunda Arc off southern Sumatra (Segment CD) and Java (Segment DE) are not considered in the present study since the location and orientation of these segments clearly suggest that the bulk of the tsunami energy from these fault planes will be directed away from Bangladesh (source directivity, Ben-Menahem and Rosenman, 1972). Moreover, source directivity as well as the presence of the landmass of India would prevent wave energy of any significance from reaching Bangladesh if a tsunamigenic earthquake were to occur in Makran Subduction Zone (Segment FG). Accordingly, only the tsunamigenic seismic scenarios originating from Arakan (segment AB) and Andaman-Northern Sumatra (Segment BC) of the Sunda Arc will be considered for the purpose of assessing the tsunami hazard to Bangladesh.

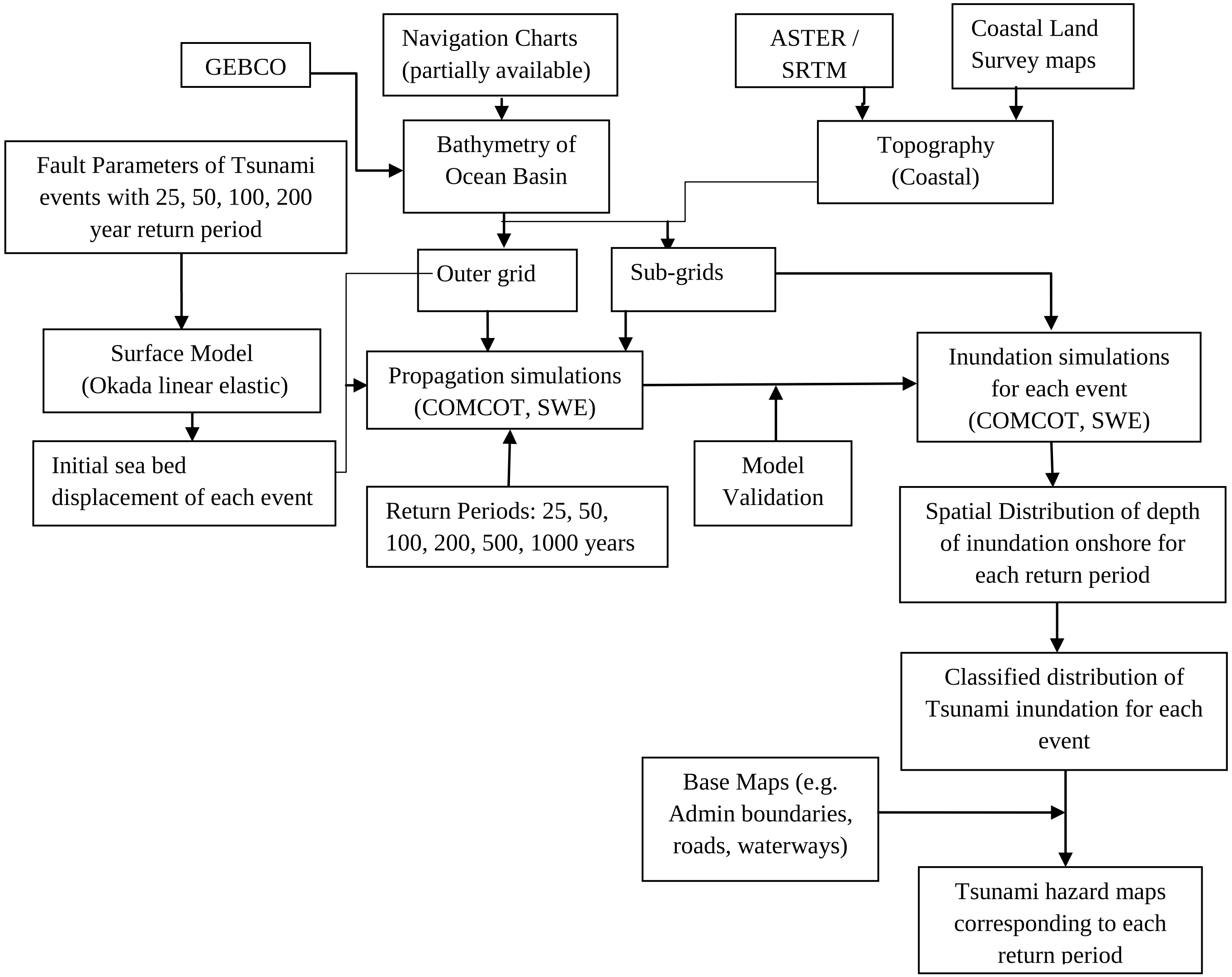


Figure 0.20: Flow chart of tsunami hazard modeling and mapping methodology (Source: modified from Jaiswal et al., 2008)

1.3.2.2 Tectonics and Past Seismic Activity

In this section, the tectonics and the seismic history of the Arakan and Andaman-Northern Sumatra subduction segments identified above are briefly reviewed.

The Northern Sumatra-Andaman zone encompasses offshore northern Sumatra and the Nicobar-Andaman Island chains. In this zone, the Indian plate is subducting obliquely beneath the Burma microplate with an estimated convergence rate of about 20 mm/yr to 40 mm/yr, with the higher rates to the south (Chlieh et al., 2007). Large earthquakes that have occurred in the Andaman-Northern Sumatra zone during the past 200 years include the events of M_w = 7.9 in 1881, M_w = 7.7 in 1941, M_w = 9.1 in 2004, and M_w = 7.5 in 2010. Moreover, about 25 earthquakes of magnitude greater than M_w = 6.0 have occurred during the past century, 11 of which occurred during the past 50 years, yielding a rate of about one event every 4–5 years (Petersen, et al., 2007). Further, preliminary paleoseismic data reported in Rajendran et al. (2007) and those in Jankaew et al. (2008) indicate that at least one predecessor to the 2004 earthquake occurred about 700–1000 years ago.

The earthquake of M_w = 9.1 in 2004 in the Andaman-Northern Sumatra segment may also have increased the stress on adjacent segments of the subduction, raising the seismic hazard at both ends of the rupture, i.e., further south off southern Sumatra as well as further north in the northern Bay of Bengal along the coast of Myanmar (McCloskey et al., 2005; Stein and Okal, 2005; and Vigny et al., 2005).

Several recent studies suggest that the Arakan trench, where the Indian plate under thrusts the South-East Asian part of the Eurasian Plate, is still an active subduction zone (Dasgupta et al., 2003; Satyabala, 2003; Nielsen et al., 2004; Socquet et al., 2006). GPS observations indicate a 23 mm/yr accumulation of back slip along the Arakan trench (Socquet et al., 2006). Nevertheless, some earlier works, for example those of Ni et al. (1989) and Guzman-Speziale and Ni (1998), have suggested that subduction along Burmese Arc is not active at present.

Past seismic activity in the Arakan subduction zone includes historical reports of a large earthquake on April 2, 1762 along the coast of Bangladesh and Mynamar, from Chittagong in the north to Foul Island in the south, causing an uplift of 3–7 m (Le Dain et al., 1984). Recent paleoseismological work has also confirmed the presence of emerged coral structures (Satake et al., 2006), of an age compatible with the 1762 earthquake (Okal and Synolakis, 2008).

Socquet et al. (2006) noted that a significant portion of the Arakan trench is elastically locked and accumulating significant deformation, and therefore, there is a high probability of occurrence of subduction earthquakes in this area. Cummins (2007) also concluded that the Arakan trench is capable of generating a giant tsunamigenic earthquake with potential for causing great loss of lives and destruction. His assessment was based on an examination of the tectonic environment, stress and crustal strain observations as well as historical earthquake activity in the Arakan subduction zone. On the other hand, no large earthquakes are documented, even in the historical record, along the northern extension of the 2004 rupture, between Great Coco Island and the southwestern tip of Myanmar, forming the western end of the mouths of the Irrawady (Okal and Synolakis, 2008).

1.3.2.3 Tsunamigenic Seismic Scenarios

Two methods are generally available for delineation of seismic scenarios for tsunami simulations, namely, the deterministic method and the probabilistic method. A deterministic tsunami hazard analysis has already been carried out for Bangladesh at a coastal level spatial resolution of 600 m under Comprehensive Disaster Management Programme (CDMP) (IWM, 2009). In view of this and as specified in the Terms of Reference (ToR), the present study incorporates probabilistic measures of the tsunami hazard so far as feasible within the typical constrains of paucity of historical data pertaining to the subduction zones.

The present study utilizes recently published results of an extensive probabilistic tsunami hazard assessment for Indian Ocean Nations including Bangladesh, reported in Burbidge et al. (2009), to delineate the earthquake magnitudes in Andaman-Northern Sumatra segment corresponding to the recurrence intervals (T_r) of 25, 50, 100, 200, 500, and 1000 years. The magnitude and the source parameters of such earthquakes corresponding to different recurrence intervals are given in Table 1.8. It must be added that the relatively short length of the available historical record of seismic events may result in a higher margin of error for the seismic scenarios with longer return periods such as T_r = 500 years and 1000 years.

Unfortunately, it is not possible to carry out such a probabilistic seismic hazard assessment for the Arakan segment at this time owing to the paucity of records of past seismic events in that part of the arc as well as due to the comparatively poor understanding of its seismo-tectonics. For example, although there is historical evidence that Arakan segment has experienced a major earthquake in 1762, there is no estimate of its magnitude. It is also not clear that it ruptured the megathrust fault specifically, nor that it generated anything more than a local tsunami (Burbidge et al., 2009). The potential for future occurrences of large tsunamigenic earthquakes in this segment is therefore unknown, particularly in a probabilistic sense.

However, Okal and Synolakis (2008) have delineated two worst-case seismic scenarios for the Arakan zone (Table 1.7), one in its northern segment (Mw = 8.6, Scenario-6) and the other in the south (Mw = 8.8, Scenario-7). Scenario-6 is a fault model inspired by a repeat of the 1762 earthquake whilst Scenario-7 is categorized as a somewhat far-fetched nevertheless feasible event to occur immediately north of the termination of the 2004 rupture. A recurrence interval of Tr > 1000 years has been assigned to these presumably low probability, worst-case events given the uncertainty in regard to their frequency of occurrence.

Table 0.7: The magnitude and the source parameters of seismic events corresponding to different recurrence intervals.

Seismic scenario	Return period (years)	Seismic zone	Mw	M0 (Nm)	Source parameters						
					Φ (deg)	**δ (deg)**	**λ (deg)**	**L (km)**	**W (km)**	**H (km)**	**Δu (m)**
1	25	Andaman	7.4	1.2x1020	10	12	90	50	40	25	2.1
2	50	Andaman	7.7	4.0x1020	10	12	90	70	45	25	4.3
3	100	Andaman	8.1	1.5x1021	10	12	90	150	65	25	5.5
4	200	Andaman	8.4	4.5x1021	10	12	90	250	85	25	7.0
5	500	Andaman	8.7	1.5x1022	10	12	90	500	95	25	10.5
6	>1000	Arakan	8.6	7.9x1021	324	20	124	470	100	25	6.5
7		Arakan	8.8	1.6x1022	20	15	90	470	175	25	7.0
8		Andaman	9.1	4.5x1022	Multi-segment source model of Ji (2005), reported in Ammon et al. (2005)						

Note: Seismic zones - Arakan (AB) and Andaman (BC) in Fig. 1.20.

Source: Burbidge et al., 2009; Okal and Synolakis, 2008

In Table 1.8, H is the depth of the fault plane; L is the length of the fault; M0 is the seismic moment; W is the width of the fault plane; Φ is the strike angle; δ is the dip angle; λ is the rake angle; Δu is the slip.

1.3.2.4 Numerical Simulations of Tsunami Propagation and Inundation

Numerical simulations of tsunami propagation and inundation were carried out by employing COMCOT (Cornell Multi-grid Coupled Tsunami Model) for all scenarios given in Table 1.8. A dynamically coupled system of two nested grids was employed to simulate the tsunami propagation from each of the seismic zones towards the shoreline of Bangladesh. The non-linear form of the depth-averaged shallow-water equations were used in the numerical simulation of tsunami inundation. The COMCOT model has been validated by experimental data (Liu et al., 1995) and has been successfully used to investigate several historical tsunami events, including the 2004 Indian Ocean tsunami (Liu et al., 1994; Wang and Liu, 2006; Wijetunge, 2009, 2012). Further details of the model including governing equations and numerical formulation can be found in Liu et al. (1998) and Wijetunge et al. (2009).

Whilst the inner, second-level grid was the same for all simulations, three different versions of outer grids were used to accommodate the different locations of the subduction segments. The bathymetric data for the outer grids employed in the simulations was obtained by interpolating GEBCO (2010) data with a resolution of 30 arc-seconds to a grid of 0.01 arc-degrees (about 1000 m) spacing. Similarly, the computational domain of the inner grid, which is embedded in the outer grid for the simulation of tsunami propagation over the continental shelf off the coast of Bangladesh was set-up at a finer resolution of 0.002 arc-degrees (about 200 m). The topographic data employed in the study comprised the coastal digital elevation model at a horizontal resolution of 50 m, provided by the Institute of Water Modeling (IWM), supplemented with spot elevation data based on the Spot Elevation Map of Survey of Bangladesh at a scale of 1: 20,000.

It must also be added that, at the outset, Okada's (1985) dislocation model was employed to obtain the initial sea surface elevation for the above co-seismic tsunami sources assuming that the sea surface follows the sea bed deformation instantaneously.

1.3.2.5 Model Validation

The tsunami propagation model set-up and formulation employed in the present study was further validated by comparing the computed water surface levels due to the Indian Ocean tsunami in 2004 (scenario-8) with available records of measurements. Only a few field observations of maximum water levels due to the tsunami in 2004 are available off the coast of Bangladesh. These include the tide-gauge record at Hiron Point (Khan et al., 2005), which shows good agreement with the computed water level (Figure 1.21). As far as the impact of the 2004 tsunami on Bangladesh is concerned, two deaths have been reported in the sea off Barisal (Uddin, 2005). The notable peak in the computed maximum tsunami heights near the seaboard of Barisal coast in Figure 1.22 (around 90 - 90.3^{o}E) is consistent with the reported casualties mentioned above.

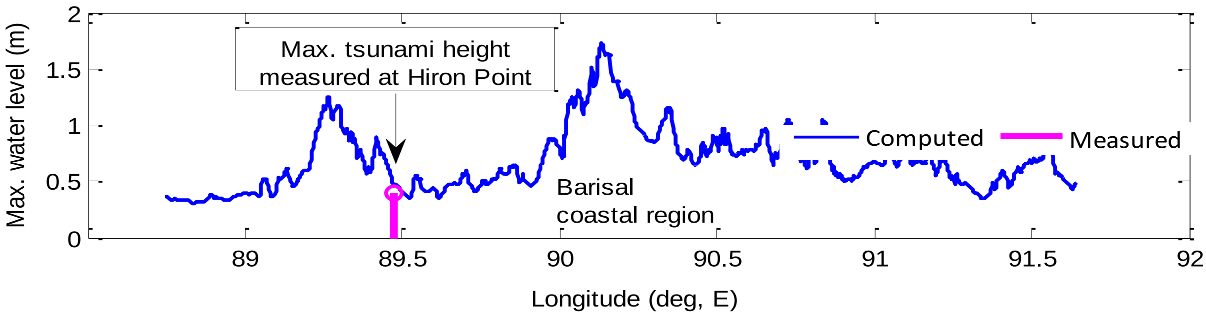


Figure 0.21: Comparison of computed maximum water levels along the coast of Bangladesh with the maximum tsunami height recorded by the tide gauge at Hiron Point

Given the scarcity of observed tsunami heights off the coast of Bangladesh, such records for the neighboring coastline of northeastern India are also utilized for model validation in Figure 3.49. It can be seen in Figure 3.48 that the recorded maximum tsunami height extracted from the tide gauge record at Paradip in northeastern India (Nagarajan et al., 2006) shows good agreement with the computed peak water levels in the vicinity.

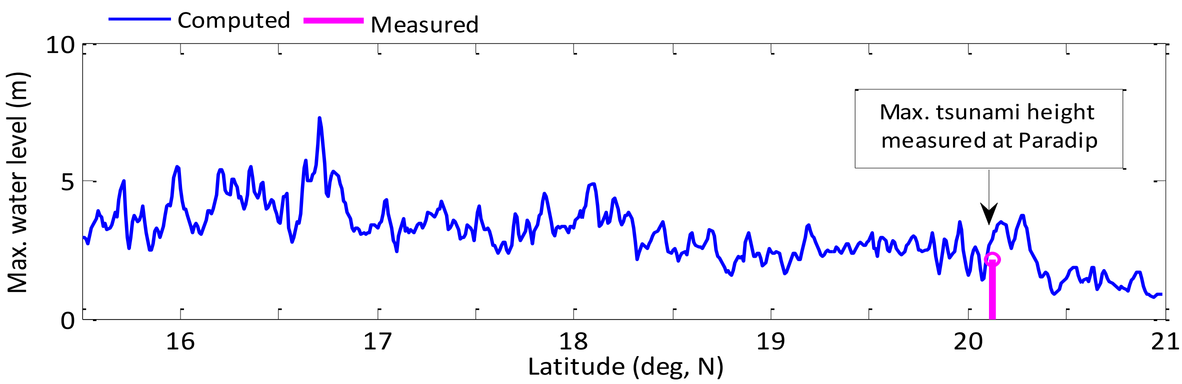


Figure 0.22: Comparison computed maximum water levels along the north-western coast of Bay of Bengal with the maximum tsunami height recorded by the tide gauge at Paradip, India

Extraction of Computed Tsunami Amplitudes off the Shoreline of Bangladesh

The computed tsunami amplitudes corresponding to each of the seismic scenarios simulated were extracted off the shoreline of Bangladesh, along the coastlines of Sundarban-Barisal-Sandwip and Chittagong-Teknaf (Figure 1.23 shows the location of these coastal areas).

Figure 0.23: Location of map showing Coastal Stretch A: Sundarban-Barisal-Sandwip, and Stretch B: Chittagong-Teknaf

Source: ADPC, 2010

Let us first consider the computed tsunami amplitudes corresponding to seismic scenarios 6, 7 and 8, with estimated recurrence intervals longer than 1000 years (Figure 1.24), representing worst-case scenarios for northern Arakan, southern Arakan and Andaman-Sumatra segments of the Sunda Arc, respectively. We see in Figure 3.51 that the maximum tsunami amplitudes near the coast of Bangladesh due to scenario-8 in Andaman-Northern Sumatra seismic zone (i.e., an event similar to that generated the tsunami in 2004) are, in general, smaller than those due to scenarios 6 and 7 in the Arakan seismic zone. Further, the computed tsunami amplitudes due to scenario-7 are larger than those due to scenario-6 along most parts of the coastline of Sundarban-Barisal-Sandwip, except in the vicinity of 89.7^{o}-90.0^{o} E and 91.25^{o}-91.55^{o} E.

However, along the coastline of Teknaf-Chittagong, scenario-6 results in larger tsunami amplitudes than scenario-7. This means that, although scenario-7 may be considered as the worst-case for most parts of the coastline of Sundarban-Barisal-Sandwip, the worst-case for the coastline of Teknaf-Chittagong is scenario-6. Accordingly, it is necessary to carry out detailed inundation modeling for coastal Bangladesh for both scenarios-6 and -7 representing the worst-case (Tr > 1000 years), and then derive a composite of the computed inundation depths so as to yield the maximum of the two cases at each grid point.

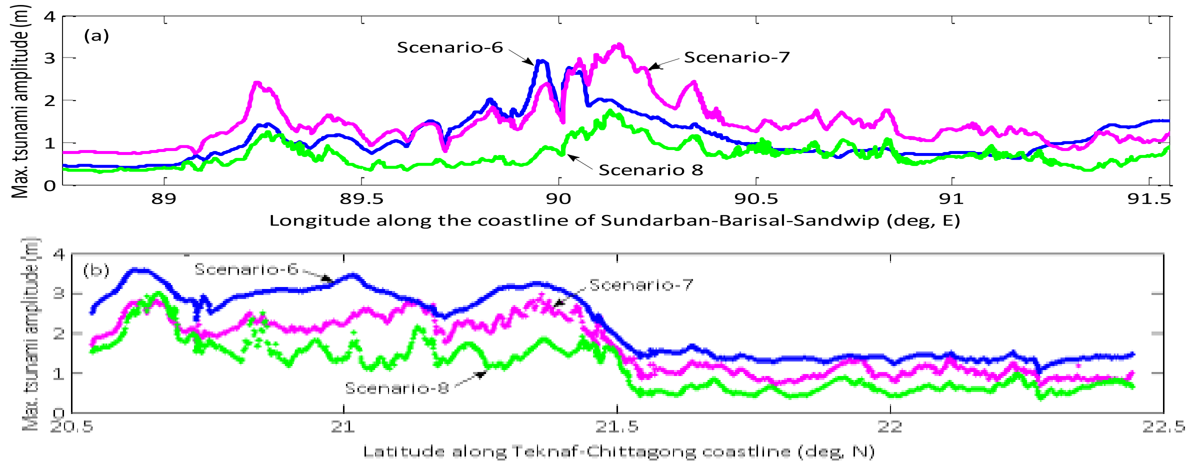


Figure 0.24: Computed maximum tsunami amplitudes corresponding to seismic scenarios 6, 7 and 8 along the coast of Bangladesh: (a) Sundarban-Barisal-Sandwip coastline, and (b) Teknaf-Chittagong coastline

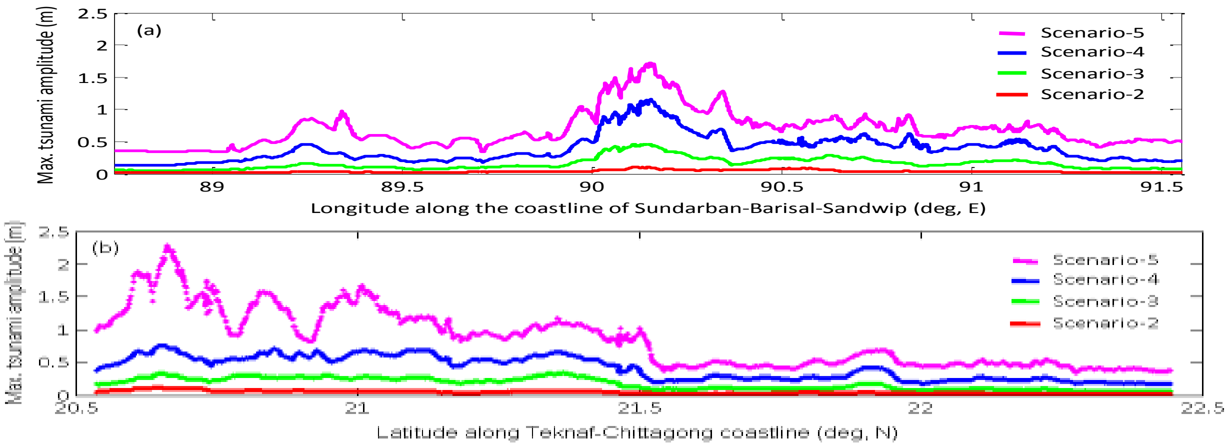


Figure 0.25: Variation of the computed maximum tsunami amplitudes corresponding to seismic scenario-5 (Tr = 500 years), scenario-4 (Tr = 200 years), scenario-3 (Tr = 100 years) and scenario-2 (Tr = 50 years) along the coastlines of (a) Sundarban-Barisal-Sandwip, and (b) Teknaf-Chittagong. The maximum tsunami amplitudes due to seismic scenario-1 (Tr = 25 years) are very small, and therefore, are not shown.

We see in Figure 1.25 that the tsunami amplitudes near the coast gradually decline with the decreasing magnitude of the respective earthquake scenarios as well as the recurrence interval. Two notable peaks in the tsunami amplitude variation along the coastline of Sundarban-Barisal-Sandwip (Figure 1.25a) can be seen at around 89.3^{o}E and at 90.2^{o}E. These peaks are on either side of the axis of the submarine canyon that approaches the near shore sea off Barisal at around 89.6^{o}E. In Figure 1.25b for the Teknaf-Chittagong coastline, the tsunami amplitudes are comparatively higher north of the latitude 21.5^{o}.

1.3.2.6 Tsunami Arrival Time

The information relating to the time it takes for the first wave of a tsunami to arrive at a given coastline is essential for emergency planning and in early warning. Accordingly, the arrival time contours corresponding to potential tsunamigenic earthquakes in the Andaman seismic zone; see scenarios 1 to 5 and 8 identified in Table 1.8 are shown in Figure 1.26. Note that the arrival times given are in minutes after the occurrence of the earthquake, and are based on the first 1 cm rise of mean water level. It must also be noted that the tsunami propagation speed and thus the arrival time does not depend on the magnitude of the earthquake. The propagation speed depends on only on the water depth, and therefore, the arrival time contours shown in Figure 1.26 are applicable to tsunamigenic earthquake of any magnitude originating in the Andaman seismic zone.

The arrival time contours in Figure 1.27 indicate that the tsunami waves first reach the western half of the Sundarban-Barisal-Sandwip coastline (segment-A) about 180 minutes after the earthquake. However, it takes 210 – 360 minutes for the tsunami to reach the eastern half of segment-A, primarily owing to the shallow coastal water in that region. We also see that the tsunami waves propagate faster along the axis of the submarine canyon, which approaches the nearshore sea off Barisal at around 89.6^{o}E. Furthermore, the southern part of the Chittagong-Teknaf coastline (Segment-B) receives tsunami waves approximately 150 – 210 minutes after the earthquake. However, it could take 210 – 360 minutes for the waves to arrive at the northern part of the Chittagong-Teknaf coastline.

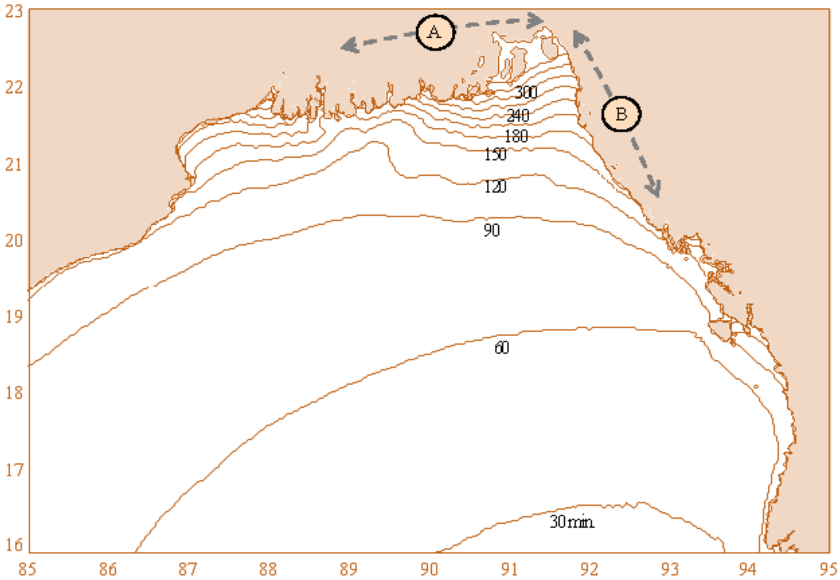


Figure 0.26: Contours of arrival time in minutes after earthquake for tsunami generated in the Andaman seismic zone (scenarios 1 to 5 and 8, in Table 1.8). Coastal Stretch A: Sundarban-Barisal-Sandwip, and Stretch B: Chittagong-Teknaf

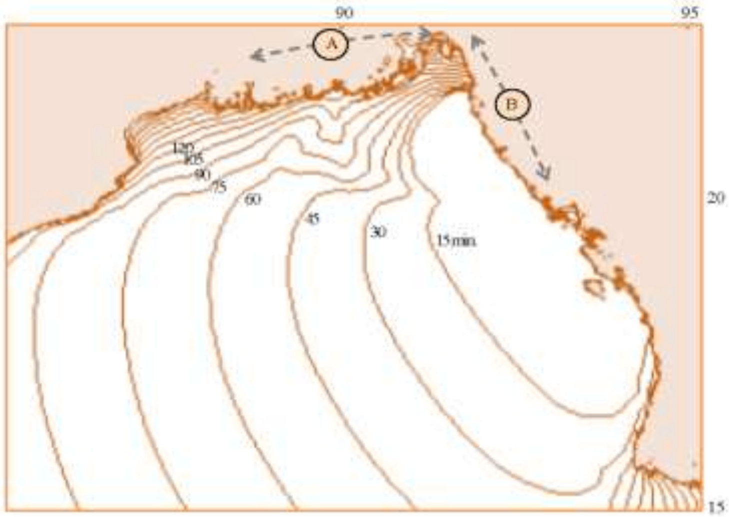


Figure 0.27: Contours of arrival time in minutes after earthquake for tsunami generated in the Arakan seismic zone (scenarios 6 and 7, in Table 1.8). Coastal Stretch A: Sundarban-Barisal-Sandwip, and Stretch *B*: Chittagong-Teknaf

The arrival time contours corresponding to potential tsunamigenic earthquakes in the Arakan seismic zone, for instance scenarios 6 and 7 identified in Table 1.8, are shown in Figure 1.27. The arrival time contours shown in Figure 3.53 are applicable to any tsunamigenic earthquake originating in the Arakan seismic zone since tsunami propagation speed does not depend on the magnitude of the earthquake.

The arrival time contours in Figure 1.27 indicate that the tsunami waves first reach the western half of the Sundarban-Barisal-Sandwip coastline (segment-A) about 120-150 minutes after an earthquake in the Arakan seismic zone. However, it could take a longer time for the waves to propagate across shallow water off the eastern half of the Sundarban-Barisal-Sandwip coastline. On the other hand, given the proximity of the fault plane, most parts of the Chittagong-Teknaf coastline (Segment-B) would receive tsunami waves almost immediately after an earthquake in the northern segment of the Arakan seismic zone.

1.3.2.7 Onshore Inundation Simulations

Tsunami onshore inundation simulations were carried out for scenarios 2, 3, 4, and 5 corresponding to estimated recurrence intervals of 50, 100, 200 and 500 years, respectively, as well as for scenarios 6 and 7 representing the worst-case with a recurrence in the order of 1000 years. No inundation simulations were carried out for scenario 1 with a return period of 25 years since the computed tsunami heights near the shore were found to be very low.

The interaction of tsunami with the tide is not explicitly simulated in the tsunami propagation model. Therefore, the initial water surface level in inundation model simulations was adjusted to “Mean High Water” sea-level condition at spring tide, thus representing a conservative sea level for the intended use of the tsunami hazard mapping. An average value of the maximum tidal range corresponding to spring tide was obtained based on data from Bangladesh Tide Tables.

1.3.3 Analysis of Hazard Assessment

The area (km^2) and percentage of inundation due to tsunami hazard of 100 years return period at division level is given in Table 1.8 and Figure 1.28.

Table 0.8: Area and percentage of inundation due to tsunami induced inundation depth in each division

Division	Area and percentage of inundation (km^2) due to Tsunami induced depth											
	< 0.5 m		0.5 - 1.0 m		1.0 - 2.0 m		> 2.0 m		Not Affected		Total affected	
	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
Barisal	81.81	0.62	50.21	0.38	27.43	0.21	88.39	0.67	12977.36	98.13	247.8	1.9
Chittagong	20.97	0.06	49.77	0.15	6.59	0.02	17.46	0.05	33813.76	99.72	94.8	0.3
Khulna	2.01	0.01	0.55	0.00	0.32	0.00	1.32	0.01	22280.02	99.98	4.2	0.02
Total Area (km^2) / %	104.79	0.2	100.5	0.1	34.3	0.0	107.2	0.2	69071.1	99.5	346.8	0.5

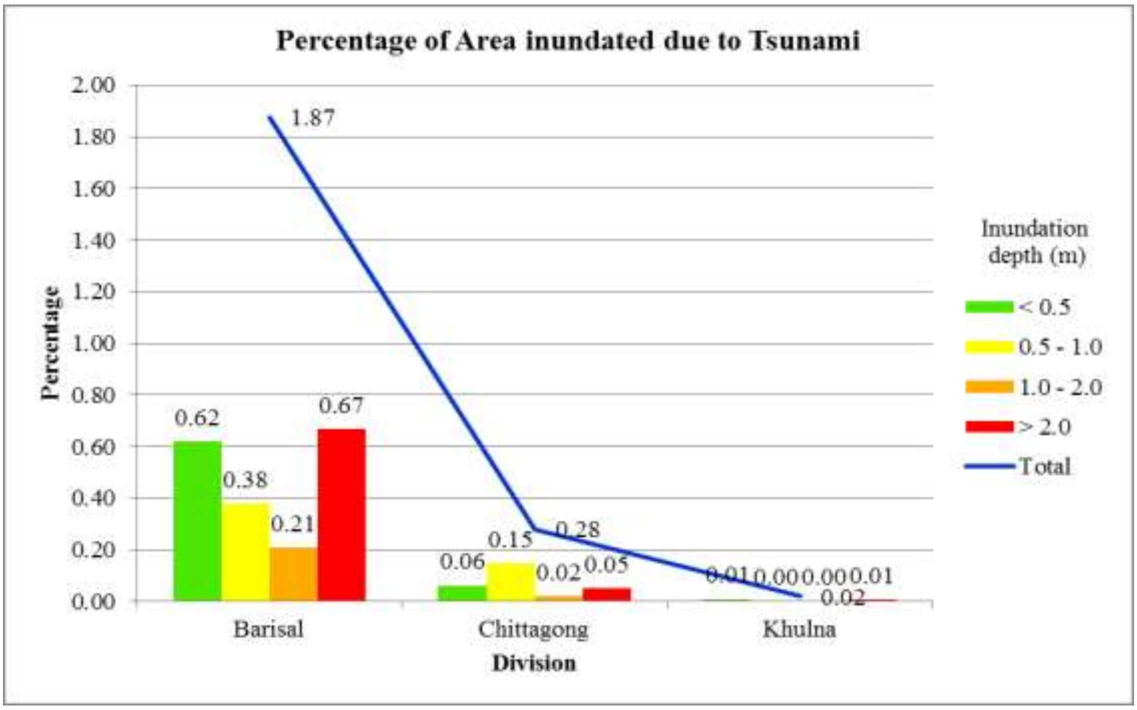


Figure 0.28: Percentage of inundation due to tsunami in each division

Area and percentage of inundation (km^2) due to tsunami induced depth in each district is given in Table 1.9.

Table 0.9: Area and percentage of inundation due to tsunami induced inundation depth in each district

Division	District	Depth and Area of inundation (km^2) due to Tsunami											
		< 0.5 m		0.5 - 1.0 m		1.0 - 2.0 m		> 2.0 m		Not Affected		Total Affected	
		Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
Barisal	Barguna	6.27	0.34	2.93	0.16	2.41	0.13	4.03	0.22	1815.67	99.15	15.6	0.9
	Bhola	27.74	0.82	11.31	0.33	9.61	0.28	30.90	0.91	3323.92	97.66	79.6	2.3
	Patuakhali	46.18	1.43	34.55	1.07	14.93	0.46	51.32	1.59	3074.33	95.44	147.0	4.6
Chittagong	Chittagong	0.00	0.00	0.00	0.00	0.04	0.00	0.35	0.01	5282.53	99.99	0.4	0.0
	Cox's Bazar	9.09	0.36	11.68	0.47	3.35	0.13	15.11	0.61	2452.62	98.43	39.2	1.6
	Feni	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.01	990.24	99.99	0.1	0.0
	Noakhali	14.07	0.38	43.94	1.19	3.85	0.10	3.19	0.09	3620.82	98.24	65.1	1.8
Khulna	Bagerhat	1.53	0.04	0.51	0.01	0.17	0.00	1.04	0.03	3955.86	99.92	3.3	0.1
	Satkhira	0.46	0.01	0.04	0.00	0.14	0.00	0.27	0.01	3816.38	99.98	0.9	0.0

1.3.4 Map Content

The tsunami hazard maps for the coastal region of Bangladesh depict the spatial distribution of inundation due to several probable seismic scenarios corresponding to recurrence intervals of 50, 100, 200, 500 and 1000 years. The maps use four color bands to classify the distribution of the level of tsunami hazard based on computed flow depths under "Mean High Water" sea-level condition at spring tide. The tsunami inundation depths shown on these maps have been computed by employing a depth-averaged, two-dimensional numerical model of tsunami generation, propagation and inundation. The model used is the Cornell Multi-grid Coupled Tsunami Model (COMCOT), which solves the non-linear shallow water equations on a dynamically coupled system of nested grids using finite difference numerical schemes.

The tsunami hazard maps depicting the probable spatial distribution of the depth of onshore inundation at Mean High Water Spring (MHWS) for several return periods (i.e., 50, 100, 200, 500 and 1000 years) are shown in Figures 1.29 to 1.33. Although a direct comparison is not possible due to differences in the seismic scenarios, the inundation depths from the present simulations are on the whole consistent with those reported in IWM (2009).

Following Walsh et al. (2003), the flow depths depicted in these tsunami hazard maps have been classified into low, moderate, and high levels of the hazard (Table 1.10). Note that the classification to be finally adopted should be discussed with the primary stakeholders, and therefore, the scheme proposed in Table 1.10 may have to be revised accordingly. Furthermore, GIS layers representing administrative boundaries, roads, waterways, etc. could be superimposed on these tsunami hazard maps, as required by the end users, subject to data availability.

Table 0.10: Classification of tsunami induced inundation depth

Depth of Inundation (m)	Hazard Level	Color code
Not Affected	Not Affected	
< 0.5 m	Low	
0.5 – 1 m	Moderate	
1 – 2 m	High	
> 2 m	Very High	

The scale of maps may be determined based on the following general guidelines provided in GRIP/UNDP (2009): 1:25,000–1: 100,000 at district level; 1: 100,000-1: 1,000,000 at provincial level; and 1: 1,000,000 or smaller at national level.

The tsunami inundation maps due to 50, 100, 200, 500 and 1000 years return period are shown in Figures 1.29, 1.30, 1.31, 1.32, 1.33 respectively.

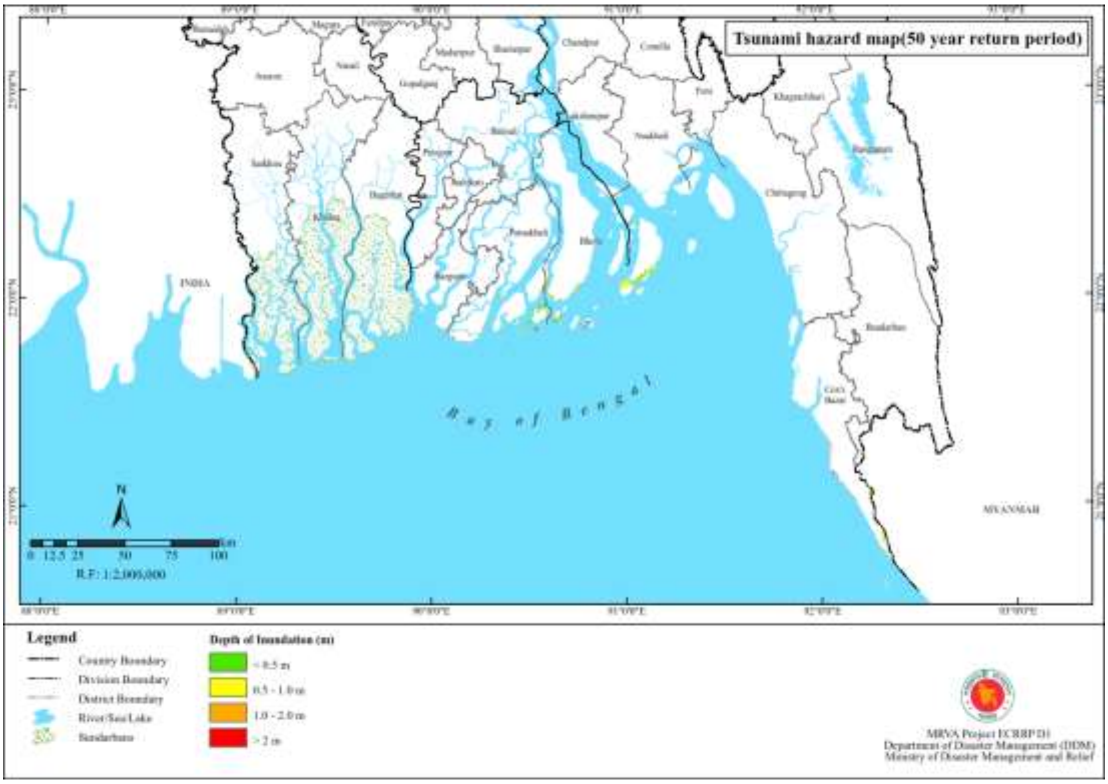


Figure 0.29: Tsunami inundation map for a 50-year return period

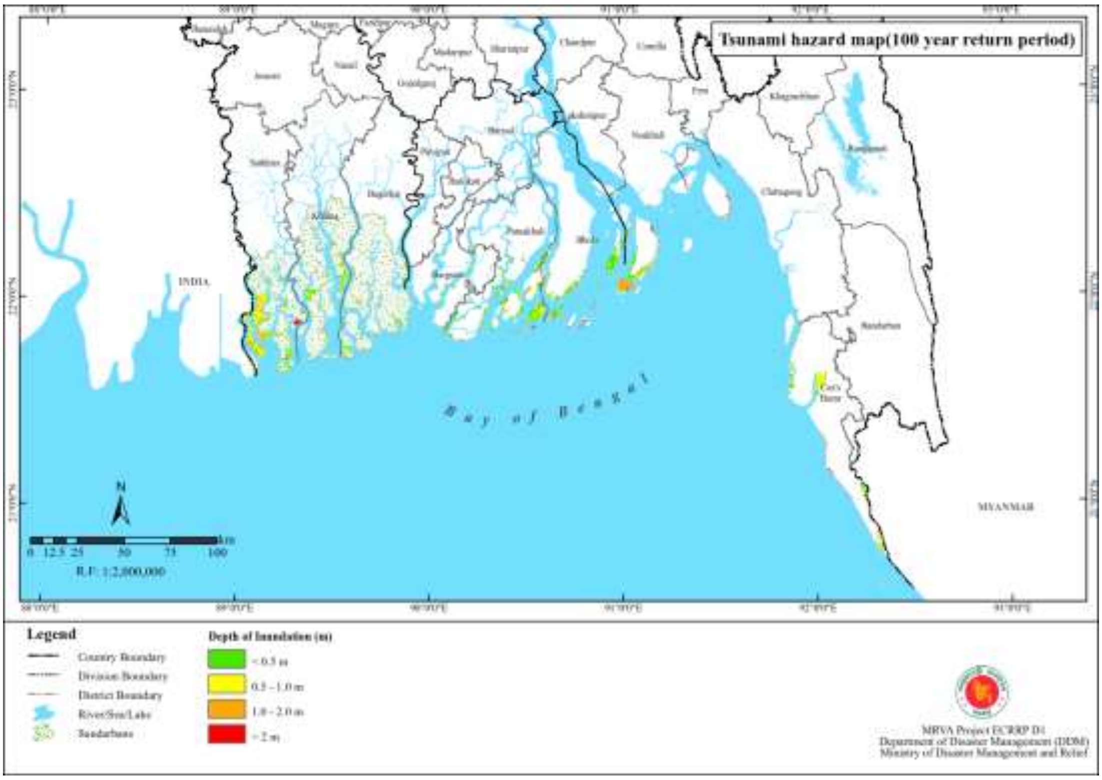


Figure 0.30: Tsunami inundation map for a 100-year return period

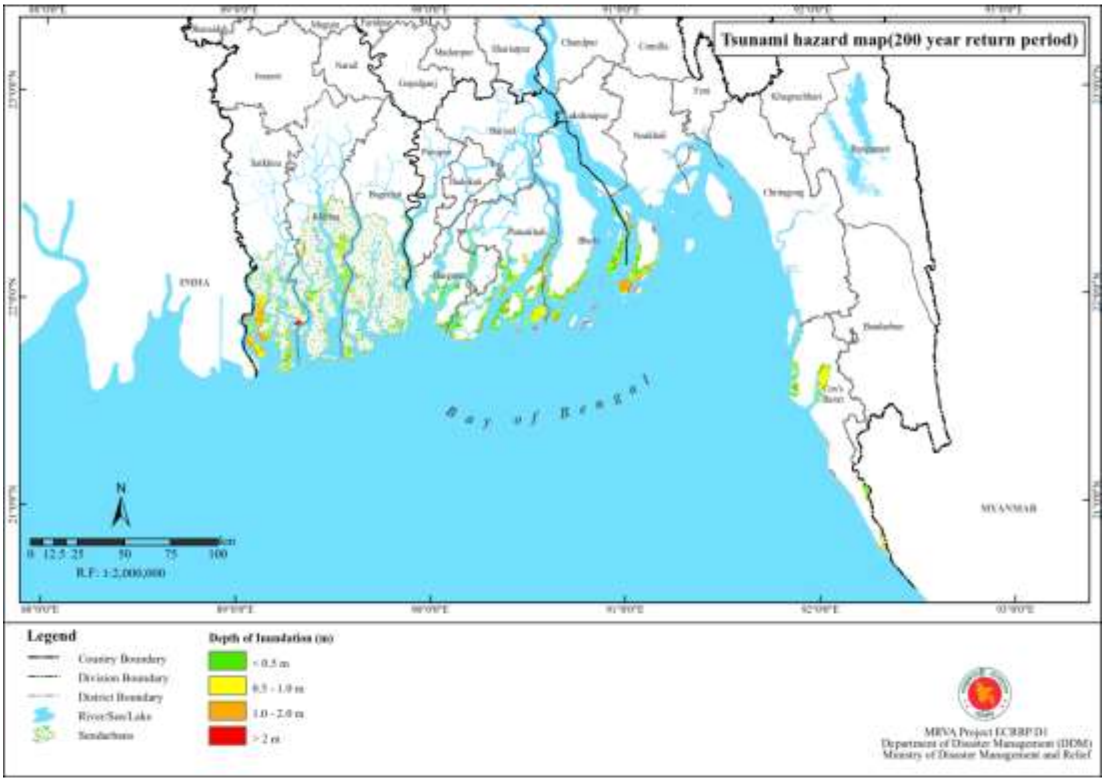


Figure 0.31: Tsunami inundation map for a 200-year return period

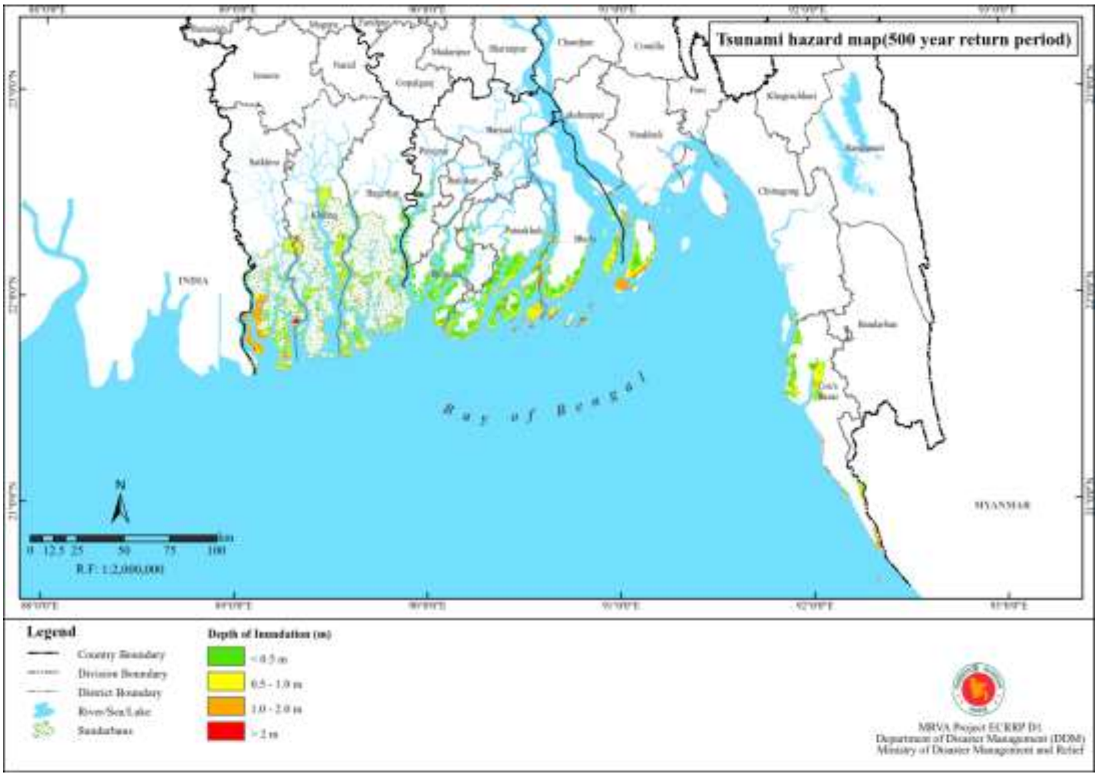


Figure 0.32: Tsunami inundation map for a 500-year return period

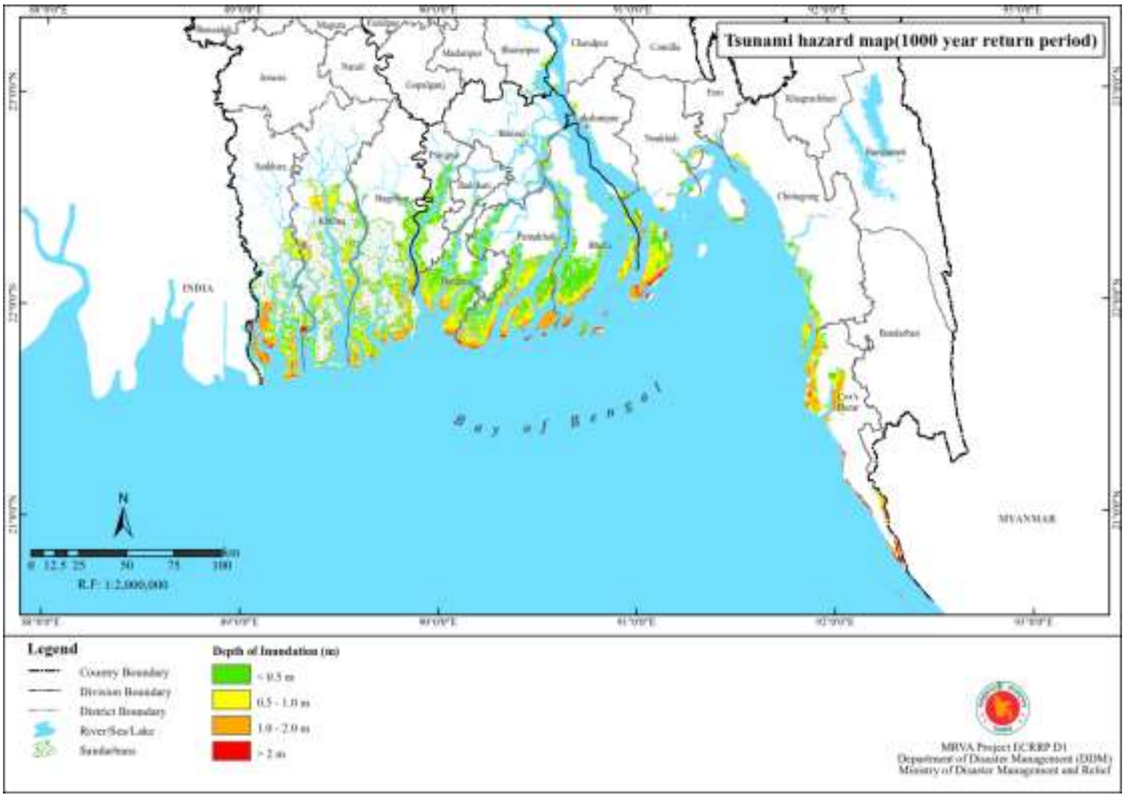


Figure 0.33: Tsunami inundation map for a 1000-year return period

1.3.5 Application of Maps

The Tsunami hazard maps can be used to reduce potential losses. The key factors for this are Awareness and Preparedness. The practical applications of this tsunami risk assessment, in both quantitative and qualitative terms, for implementation into mitigation strategies for the terrestrial and marine environments include:

- Building Codes (potential damage due to wave action and flooding)
- GIS Mapping
- Land-Use Planning (taking note of wave action and flooding)
- Disaster Planning (in identified hazard zones)
- Emergency Management
- Emergency Personnel Training (necessary aspects relevant to marine situations)
- Rescue and Response (marine situations related to shipping, cargo, tourist, inter-islands fishing community, recreational boating)
- Insurance Needs
- Community Education
- Simulated Tsunami Exercises

1.3.6 Special Remarks

Limitations

One limitation is that the resolution of numerical modelling is no greater or more accurate than the bathymetric and topographic data used. This means that the resolution of modelling, and consequently, that of the final hazard maps depends upon the resolution of available data. The availability of bathymetry charts from Bangladesh Navy is not covering the entire coastal area, which is showing in Figure 1.34. In view of this globally available best bathymetry data i.e. GEBCO is used in this study.

Since the initial condition for the modelling of tsunami generation is determined by the displacement of the ocean bottom along the fault line, another possible source of error is in the earthquake model. Furthermore, the recurrence estimates of seismic scenarios in the subduction segments concerned are often constrained by the relatively short length of data pertaining to historical seismic activity.

The maps are derived from consideration of seismogenic tsunami hazard only and any other potential tsunami generating mechanisms such as landslides are not included. Further, any possible ground subsidence or uplift in the coastal areas as a result of seismic activity is also not included due to lack of sufficiently reliable data for the subduction zones concerned.

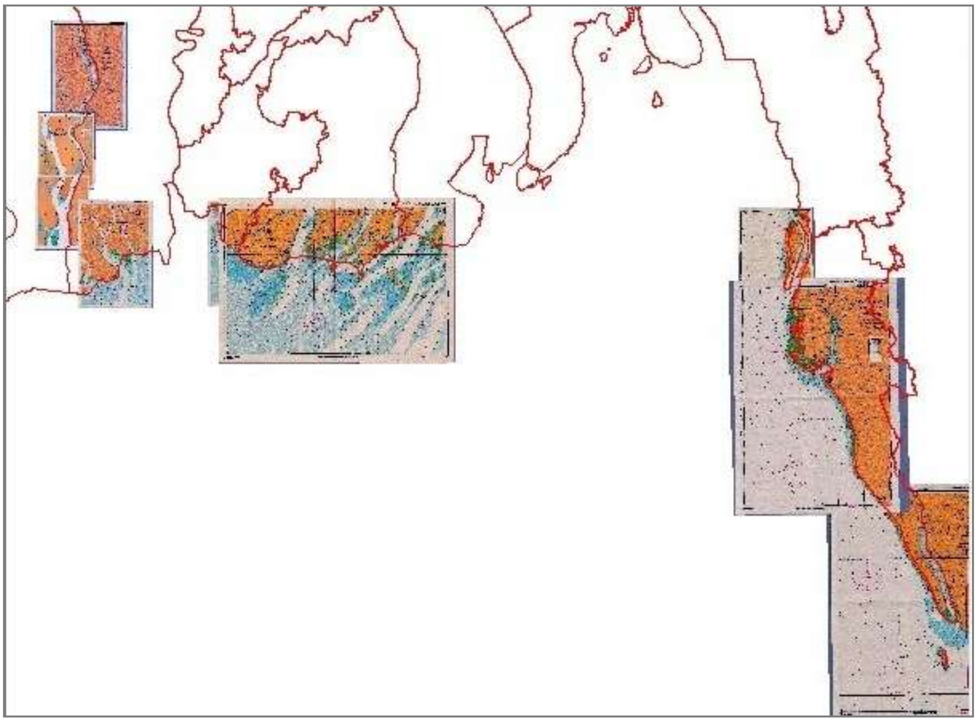


Figure 0.34: Available bathymetry charts from Bangladesh Navy

Source: Bangladesh Navy

It must also be added that tsunami models at present do not explicitly account for all means of energy dissipation for a tsunami wave surging onshore, particularly over an urban landscape. For instance, although energy dissipation due to bottom friction is included in the present tsunami model, dissipation due to turbulence is not explicitly formulated.

1.3.7 Recommendations

These tsunami hazard maps are intended for use in coastal disaster risk mitigation planning, evacuation planning and in public education and awareness activities. The maps, and the information presented therein, are not legal documents and should not be used for any regulatory purpose.

1.4 Technological Hazard

Industrialization in Bangladesh has been growing very rapidly during the last few decades and it has been greatly contibuting to the development of the country. The industrial sectors contributed 28.6 percent of the country's total GDP in 2011 (Paul et al., 2013). Textiles and clothing, leathers, pharmaceuticals and chemical industries are the main sectors that play a major role in the country's economic growth and provide a significant contribution to employment in Bangladesh. Textile and garment industries are the main source of the country's export earnings, earned USD 19 billion in the year to June 2012. Ready-made garments constitute 80 percent of the country's annual export and 15 percent of the country's GDP (Mazedul Islam et al., 2013). In the leather industry sector, there are around 220 tanneries located in Bangladesh, though only 113 of them are in effective operation (Paul et al., 2013). Most of the leather industries are located in the Dhaka city while the rest scattered all over the country. Hazaribagh area of Dhaka city is the center of the leather industry in Bangladesh. These tanneries shared 3 percent of the country's export in 2010-11, and made around USD 500 million in total earnings. The pharmaceutical sector is one of the most developed industrys among the manufacturing in Bangladesh, with around 250 companies operating in the market (Mandal et al., 2013).

Although the industrial sectors have been making a very important contribution to the economic growth of Bangladesh, these industries have also caused increasingly serious health, safety, and environmental problems. Technological disasters caused by chemical, mechanical, civil, electrical or other process failures in an industrial plant occur due to accident, negligence or incompetence. Common technological hazards in Bangladesh are accidents in garment industries, pollution caused by tannery industries and ship breaking industries, and chemical accidents. Accidents in garment industries are quite common and since 1990, more than 1,800 workers have been killed due to building collapses and fire related accidents. It is evident that most of these accidents happen as lack of safety standards and poor building construction. The stairs and floors of the buildings have been used as storage places for inflammable chemicals used in this industry, and there are narrow aisles for firefighters to enter and rescue. The electrical conditions are crude and unsafe and most of the workers work in a crowded condition with exposed machines. In the leather industry, it has been reported that only about 20 percent of the chemicals used in the tanning process is absorbed by leather, and the rest is released as waste. The direct discharge of these wastes has contaminated the ground and surface water with dangerously high concentrations of chromium, as well as cadmium, arsenic, and lead. The ship breaking industry in Chittagong, one of the largest in the world, is emerging as another type of technological hazard causing pollutions. Many of these ships contain highly toxic materials and unprotected workers often manually handle poisonous chemicals exposing themselves to serious health risks. According to the report published by the Young Power in Social Action (YPSA), more than 400 workers have died while dismantling ships in Chittagong coastal area over the last 20 years.

Most industries in Bangladesh are chemical-based industries including textile, leather, pharmaceutical, fertilizer, cement, dyeing, pulp and paper, edible oil, PVC, water treatment, etc. Textile industries, as well as other industries, use different types of chemicals from Chlor-Alkali and its chlorinated product, and Hydrogen peroxide plant in many processing steps especially in wet processing factories (Mandal et al., 2013; Salahuddin, 2011). Chemical accidents involved Extremely Hazardous Substances (EHSs) causing serious damage to people, property, and environment. According to the database compiled by the FACTS (Failure and Accidents Technical Information System), at least 29 accidents have been reported in Bangladesh from 1974 to 2008.

A comprehensive planning and disaster management of technological hazards requires a detailed industrial hazard analysis that involves hazard identification, vulnerability analysis and risk analysis (USEPA, 1987). Identification of high priority hazards should be addressed in the emergency response planning process by considering all potential scenarios of hazards.

Such a complete analysis could vary from site to site depending upon the availability of data on individual plants.

Definition of Technological Hazard

The definition of technological hazard according to the UNISDR refers to a man-made hazard originating from technological or industrial conditions, including accidents, dangerous procedures, infrastructure failures or specific human activities that may cause death, injury, illness or other health impacts, property damage, livelihoods and services loss, social and economic disorder, or environmental damage (UNISDR, 2009). An event or subsequent events related to natural hazards can also trigger the technological hazards, as in the case of the explosions of nuclear reactors in Fukushima, Japan due to an earthquake followed by a tsunami. Examples of technological hazards include industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires, and chemical spills (PAHO, 2012).

A Chemical hazard is the probability of occurrence of chemical releases involving one or more hazardous chemical substances from industrial or plant facilities into surrounding environments. It can occur at any stage of industrial activities and production processes, including extraction, processing, manufacture, transportation, storage, use, and disposal. Release of damaging substances usually occurs in the form of toxic emissions, explosions, fires, spills, leaks or wastes. Releases could be sudden and intense, as in a power-plant explosion, or gradual and extensive, as in the progressive leakage of improperly disposed toxic wastes. Chemical hazards may happen due to internal factors (e.g. engineering or system failures) or external factors (e.g. human errors, extreme natural events). It is a combination of industrial systems, people, and environments that also include geological, atmospheric, ecological, psychological and social components. When these hazard occurrences exceed human and environmental systems coping capabilities, they could lead to catastrophic industrial disasters, causing loss of human life and property including adverse effects on the environment (SADKN, 2009).

1.4.1 Technological Disasters in Bangladesh

Accidents in Garment Industry

Industrial fire accidents and building collapses in export-oriented garment factories frequently occur in Bangladesh, which continue to kill workers. Being the number one export earner in the country, at least 1.5 million workers are employed in this industry, most of them women who keep the industry going but they are very vulnerable when exposed to such incidents. Since 1990, more than 1,800 deaths have been reported due to accidents in garment industry in Bangladesh (Table 1.12). The number keeps increasing even though these incidents are repeated throughout the years, and most of the cases could have been avoided. In many cases, the accidents happened due to the lack of safety standards in factories. Unplanned multistoried buildings with a limited number of emergency exits and main gates condition that are usually locked, coupled with lack of safety evacuation procedures and training for workers when a fire breaks out, results in a disastrous panic, stampede and deaths when fires occur (Tahmina and Khanam, 2010). New buildings, including factories, are required to follow the Bangladesh National Building Code 1993 (BNBC, 1993), which was published in 1993 and became legally binding in 2006. The regulation provides extensive provisions for designing and constructing buildings for safety measures. However, a weak law enforcement leads to poor building construction and safety design in many factories (Wadud et al., 2014).

The most recent accident in garment industry, and one of the worst technological disasters in history, was the collapse of eight-storied Rana Plaza in Savar district in Dhaka on 24 April 2013, which killed more than 1,100 workers and seriously injured over 2,000 people. The accident happened just months after a fire accident in the Tazreen Fashions factory in the Ashulla district of Dhaka on 24 November 2012, which killed around 124 people and injured another 200.

Table 0.11: Deaths due to accidents in garment industries in Bangladesh

Year	Number of deaths
2013	1,160
2012	124
2011	2
2010	50
2006	95
2005	87
2004	73
2002	12
2001	24
2000	60
1997	49
1996	22
1995	9
1994	5
1993	12
1991	5
1990	32

Sources: Tahmina and Khanam, 2010; Stein and Partners, 2014

Pollution Caused by Tannery Industries

Tannery industries cause serious environmental problems to ground and surface water. Liquid effluents and solid wastes with high concentrations of chromium, lead, sulfide, cadmium, and arsenic directly discharge into low lying areas, river and natural canals without proper treatment. In Hazaribagh area, the center of tanning industries of Bangladesh, the wastewater is discharged into a stagnant ponds alongside the flood protection embankment between the Buriganga River and Hazaribagh area. This wastewater is then dumped into Buriganga River. The tannery wastewater is retained in the ponds for prolonged periods of time, allowing the dissolved constituents from the wastewater to percolate the subsurface. These process can contaminate the groundwater resource, reduce the water quality of the rivers, and finally pose a significant threat to the limited water supply by changing taste and odor, growth of aquatic weeds, and other aquatic life (Zahir and Ahmeduzzaman, 2012). In the short and long term, repeated exposure to toxic chemicals can also cause health problems to workers, mostly due to lack of concern on protective equipment supplies for workers such as gloves, masks, boots, and aprons (HRW, 2012).

Pollution Caused by Ship Breaking Industries

According to the report published by Young Power in Social Action (YPSA), ship breaking is the process of dismantling an obsolete vessel's structure for scrapping or disposal. Ship breaking activities are being practiced in the coastal areas, generally at a pier or dry dock or dismantling ship. It includes a wide range of activities and challenging process, from removing all gears and equipment to cutting down the ship's infrastructure. Environmental, safety, and health are the main issues related to this industry.

In Bangladesh, the ship breaking industries began in 1969 and since then it has been known as a profitable industry, providing the country's main source of steel, generating a large amount of tax revenue, and employing more than 50,000 workers. Chittagong is the center of the ship breaking industry in Bangladesh. In 2006, there were 24 ship breaking yards in this area, extending over 14 km along Fauzdarhat to Kumira Coast.

Despite having great economic benefits, a lack of consideration has been given to safety and environmental friendly practices. Scrapped ships contain a wide range of hazardous wastes, highly toxic Persistent Organic Pollutants (POP's), asbestos fibers, heavy metals (mercury lead, arsenic, chromium, and others), and thousands liters of oil pollution (engine oil, bilge oil, hydraulic and lubricants oils and grease). These toxic and disposable materials are often discharged and spilled from scrapped ships and get mixed with sand, soil, and sea water, which in turn has a negative impact on coastal environment and biodiversity.

Moreover, the ship breaking industries are likely to cause work-related injuries and death, and health problem to workers. Accidents frequently occur in the ship breaking yards. Over the past 20 years, more than 400 workers have been killed and 6,000 were seriously injured. Workers in the ship breaking yards suffer from many diseases that may be due to living in unhealthy conditions, such as problems with eyesight, difficulty in breathing or asthma, gastric problems, skin diseases, and other infections.

Chemical Accidents

FACTS (Failure and Accidents Technical Information System) is a comprehensive database that contains information of more than 24,000 accidents with hazardous materials all over the world. It was developed by the TNO Industrial and External Safety of the Netherlands, and now continued by the Unified Industrial and Harbour Fire Department in Rotterdam-Rozenburg. The FACTS collected information on accidents, and associated hazardous materials or dangerous goods, that have occurred over the past 90 years. The information recorded in the database is often obtained from professional sources, such as accident reports made by companies, government agencies, or from publications in technical periodicals and other literature. The information from a number of sources is confidential and treated with strict anonymity. The accident database recorded in FACTS is presented on three different informational levels that can be accessed online. Level 0 is the "accident table" and it provides free information containing an overview of the general description of the selected accidents. Level 1 is the "accident abstract", containing coded identification and extends with a summary description to give more insight on the accidents subject and its event chain. Level 2 is the "extended abstract" which, if available, contains the complete textual information about the accident.

According to the FACTS database, there were at least 29 accidents involving chemical materials in Bangladesh from 1974 to 2008. The detailed lists of the chemical accidents based on the Level 0 of the FACTS database are shown in Table 1.12. The information provided in the database includes the activities and location of the accidents, chemical materials involved in the accidents, causes of accidents, and occurrences or subsequent events that have happened during the accidents. This basic information is important to understand the nature of chemical accident in Bangladesh, however, in order to perform hazard identification and risk assessment for the specific plants, it is necessary to obtain more information related to the quantity of chemical materials, the specific location of facilities or plant or transport, the type and design of chemical container or vessel, number of fatalities, chronology of accidents, etc.

Table 0.12: List of chemical accidents in Bangladesh

No	Year	Activity	Location	Chemicals involved	Causes	Occurrences or events
1	2008	Transshipment	River	Urea, Fertilizer N.O.S.	Unknown	Collision, Crack, Firefighting/Emergency response, Human-operations, Human-operations, Load/Stow, Overturn/Capsize, Recover, Remove, Subside/Sink
2	2008	Pipe transport	River	Natural gas (pressurized)	Human-failure	Block-of-system, Burst/Rupture, Collapse/Destroy, Drive, Drive-out, El-power-brake, Explosion, Fire, Firefighting/Emergency response, Overfill/Overload, Repair, Wrong-position
3	2008	Transshipment	Fuel station	Natural gas compressed (CNG)	Human-failure	Construction work, Defective-working, Drive, Explosion, Fill
4	2008	Inland navigation (river)	River	Urea, Fertilizer Phoshate	-	-
5	2008	Navigation (marine)	Harbor/port/dock	Urea, Fertilizer Phoshate	-	-
6	2007	Road transport	Road/highway/ freeway/motorway	Natural gas compressed (CNG)	Unknown	Collision, Drive, Drive-out, Explosion, Fire, Operator error, Traffic-interruption
7	2007	Road transport	Road/highway/ freeway/motorway	Explosives, Natural gas compressed (CNG)	Sabotage/Vandalism / Terrorism	Blow-away, Explosion
8	2007	Inland navigation (river)	River	Urea, Fertilizer N.O.S.	-	-
9	2005	Winning	Winning area	Natural gas (pressurized)	Management-failure	Blow-away, Blowout, Defective-working, Drilling, Evacuation, Fire, Firefighting/Emergency response, Management-failure, Pollution/Contamination, Smoke-emission, Vibration
10	2005	Winning	Winning area	Natural gas (pressurized)	Unknown	Blowout, Disperse/Spread, Drilling, Evacuation, Explosion, Fire, Firefighting/Emergency response, Overpressure, Pollution/Contamination, Release, Safety-measures
11	2003	Transshipment	Harbor/port/dock	Sulphur	Technical-failure	Fire, Firefighting/Emergency response, Ignition, Unload, Wrong-action
12	2003	Transshipment	Parking	Crude oil	Natural-cause	Collision, Natural event, Unload
13	2003	Use/application	Factory	Inflammable gas	Unknown	Blow-away, Explosion, Fire,

No	Year	Activity	Location	Chemicals involved	Causes	Occurrences or events
						Firefighting/Emergency response
14	2002	Transshipment	River	Formaldehyde	Unknown	Drive, Fall, Load/Stow, Overfill/Overload, Safety-measures, Wrong-stowage
15	2000	Pipe transport	Home	Natural gas (pressurized), Methane (gas)	Sabotage/Vandalism / Terrorism	Blow-away, Collapse/Destroy, Explosion, Fill, Fire, Firefighting/Emergency response, Human-operations, Ignition, Release, Remove, Wrong-action, Wrong-action, Wrong-composition
16	2000	Use/application	Shipyard	Inflammable gas	Unknown	Explosion, Firefighting/Emergency response, Human-operations, Ignition, Release, Smoke-emission
17	2000	Use/application	City	Inflammable gas	Unknown	Explosion, Fill
18	1999	Use/application	Shipyard	Iron (steel), Acethylene	Unknown	Explosion, Fire, Firefighting/Emergency response, Human-operations, Welding/Cutting
19	1999	Use/application	Shipyard	Inflammable gas	Unknown	Explosion, Fire, Welding/Cutting
20	1997	Winning	Winning area	Natural gas (pressurized)	Management-failure	Abnormal conditions, Blowout, Collapse/Destroy, Damage, Drilling, Evacuation, Fire, Firefighting/Emergency response, Management-failure, Release, Safety-measures
21	1994	Inland navigation (river)	Sea	Diesel oil, Fuel oil	Unknown	Subside/Sink
22	1993	Inland navigation (river)	Harbor/port/dock	Benzine (FP<21/C) Diesel oil	Human-failure	Explosion, Fire, Maintenance, Repair
23	1993	Navigation (marine)	Harbor/port/dock	Paraffin wax, chemical N.O.S	Unknown	Fire, Firefighting/Emergency response
24	1991	Processing	Chemical factory	Carbon dioxide (gas), Carbamate (Liquid), Ammonia	Technical-failure	Blast-wave, Blow-away, Burst/Rupture, Cooling, Disperse/Spread, El-power-brake, Explosion, Fire, Firefighting/Emergency response, Human-operations, Ignition, Incorrect environment., Maintenance, Release, Smoke-emission
25	1987	Storage	Winning area	Crude oil	Human-failure	Explosion, Fire, Firefighting/Emergency response, Ignition, Unpermitted-smoking, Wrong-action
26	1987	Storage	Storage/depot	Sulphur, Potassium, Inflammable chemicals	Unknown	Fire, Firefighting/Emergency response

No	Year	Activity	Location	Chemicals involved	Causes	Occurrences or events
27	1986	Inland navigation (river)	Harbor/port/dock	Inflammable gas	Unknown	Explosion, Fire, Firefighting/Emergency response, Ignition
28	1985	Use/application	Factory	Chlorine	Human-failure	Burst/Rupture, Drive, Fall, Pollution/Contamination, Release
29	1974	Use/application	Chemical factory	Ammonia	Sabotage/Vandalism /Terrorism	Collapse/Destroy, Explosion, Ignition, Release

Source: (http://www.factsonline.nl/)

Spatial Distribution of Industries in Bangladesh

The main industries in Bangladesh are textiles or garments, chemicals (pharmaceuticals and fertilizer), leather or tanneries, food processing, natural gas, jute, shipbuilding, sugar and distillation, tobacco, metals, petroleum, power, paper and pulp. The spatial distribution of industries in Bangladesh by types and districts is shown in Figure 1.35.

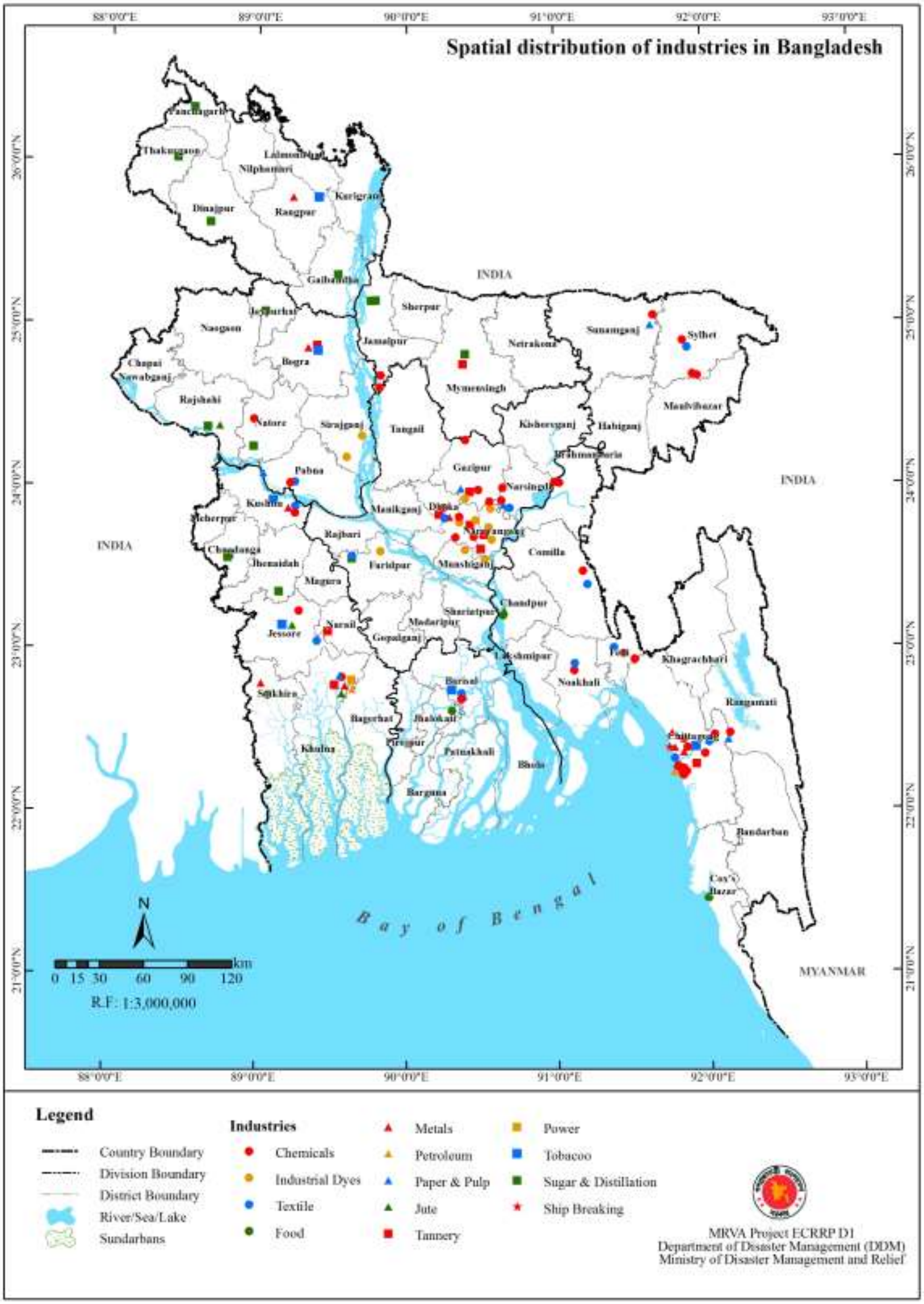


Figure 0.35: Spatial distribution of industries in Bangladesh

Source: Ministry of Industries, 2013

Dhaka and Chittagong are the main districts where most industries are located, while the rest are scattered throughout the country. Table 1.13 shows the type of industries and their district location. Due to lack of detail in available data, hazard assessment was only conducted for some chemical industries that have enough information, especially in government-owned industries.

Table 0.13: Distribution of industries in Bangladesh

Type of industry	Location
Chemical	Chittagong, Barisal, Khulna, Noakhali, Feni, Jessore, Comilla, Dhaka, Kushtia, Gazipur, Narsingdi, Brahmanbaria, Pabna, Natore, Jamalpur, Sylhet, and Sunamganj
Food	Cox's Bazar, Jhalokati, Satkhira, and Chandpur. Dyes industries in Munshiganj, Faridpur, Narayanganj, Dhaka, Gazipur, and Sirajganj
Dyes	Munshiganj, Faridpur, Narayanganj, Dhaka, Gazipur, and Sirajganj
Jute	Khulna, Jessore, Chandpur, and Rajshahi
Leather	Dhaka, Chittagong, Khulna, Narail, Narayanganj, Manikganj, Gazipur, Mymensingh, and Bogra
Metal	Chittagong, Barisal, Khulna, Satkhira, Dhaka, Kushtia, Bogra, and Rangpur
Paper and pulp	Chittagong, Khulna, Narsingdi, Gazipur, Pabna, and Sunamganj
Petroleum	Bagerhat
Power	Khulna
Sugar and distillation	Jhenaidah, Faridpur, Chuadanga, Natore, Rajshahi, Mymensingh, Joypurhat, Jamalpur, Gaibandha, Dinajpur, Thakurgaon, and Panchagarh
Textile	Chittagong, Barisal, Noakhali, Feni, Jessore, Comilla, Faridpur, Dhaka, Narsingdi, Kushtia, Pabna, and Sylhet
Tobacco	Chittagong, Barisal, Jessore, Kushtia, Bogra, and Rangpur

Source: Ministry of Industries, 2013

Government-owned Industries in Bangladesh

Government-owned or state-owned companies are often referred as Public Sector Enterprises. These enterprises are wholly or partly owned by the Government of Bangladesh, and have been actively involved in almost all areas of the economy, producing marketable goods and services with a sizeable volume of resources. The Public Sector Enterprise consists of financial and non-financial public enterprises. The financial sector includes a nationalized commercial bank, development financial institutions, and insurance sector. The non-financial sector has 40 enterprises that belong to seven broad sectors: 1) industrial, 2) power, gas and utilities, 3) transportation and communication, 4) commerce, 5) agricultural, 6) service, and 7) construction.

Bangladesh Chemical Industries Corporation (BCIC) now has 13 large and medium size industrial enterprises engaged in producing a wide range of products such as urea, TSP, paper, cement, insulator, sanitary ware etc. BCIC is also involved in ten joint venture enterprises that are engaged in the manufacture of medicine, insecticides, safety matches, paper, packaging, paper converting, etc. Bangladesh Small and Cottage Industries Corporation (BSCIC) is managing small and cottage industries in the country, providing facilities to the existing and new entrepreneurs to expand and develop their markets and to stay and sustain in the competitive environment. Bangladesh Sugar and Food Industries Corporation (BSFIC) is dealing with production of sugarcane and maintain stability of sugar price in the domestic market. Bangladesh Steel Engineering Corporation (BSEC) is established for developing infrastructural facilities of the country, creating base for industrial growth, producing engineering product to make human and material movement faster and easier, and developing sea and river transportation system. BSEC now has 13 enterprises, though only nine are in operation. Bangladesh Petroleum Corporation (BPC) is dealing with importation of crude oil and refined oil, lubricant, refining of crude oil, and distribution and marketing of fuel oils, lubricants and other petroleum products in the country.

Information on chemical-based industries owned by the government has been provided for this project by the Bangladesh Ministry of Industries, includes BSFIC, BCIC, BSCIC, and BSEC. As for the BPC, only the information of its spatial location is available. Figure 1.36 shows the distribution of the chemical-based industries owned by the government by districts. Dhaka and Chittagong are the center of industry in Bangladesh.

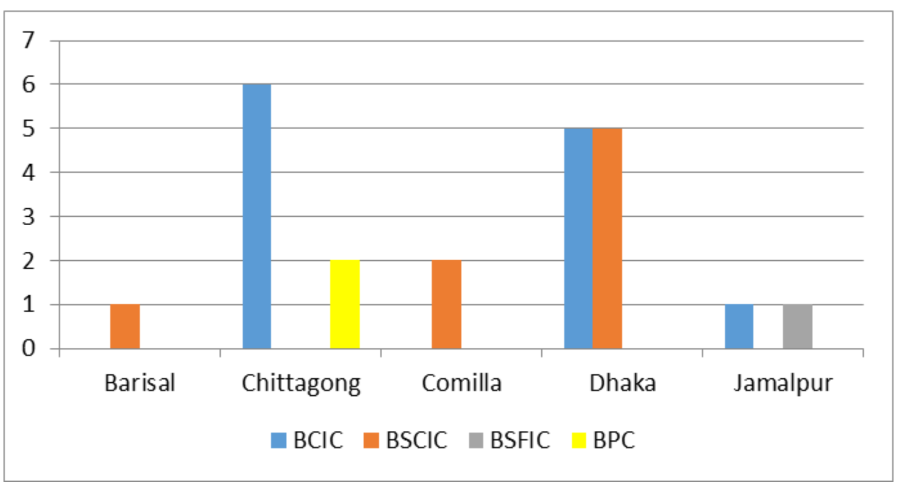


Figure 0.36: Distribution of the Government-owned industry in Bangladesh by district
Source: MoI, 2013

Keeping in view of the various types of industries in Bangladesh, an industrial hazard assessment will be possible only when relevant data is available. With this in mind, the broad objectives of this study are listed below.

Objectives

The main objective is to conduct a comprehensive study to understand the characteristics of technological hazards and disasters in Bangladesh. The specific objectives are:

1. To understand the characteristics of technological hazard and spatial distribution of industries in Bangladesh; and
2. To conduct a chemical hazard assessment to support safety issues of chemical-based industries in Bangladesh.

1.4.2 Methodology

Chemical hazard assessment requires detailed information on specific plant or industrial facilities, and an appropriate hazard model to simulate the chemical releases for different scenarios. Chemical hazard identification provides information on specific plants that have the potential to cause disasters due to hazardous materials release. It includes information on dangerous chemical substances, the quantity of material, the location of facilities or plant, the type and design of chemical container or vessel and the nature of hazards (related to the scenarios that could happen if the materials release) (EPA, 1987). A semi-quantitative approach of Seveso Directive and a quantitative method of ALOHA was applied on industrial plants that have sufficient data.

1.4.2.1 Seveso Directive

The regulations and practices to address safety issues of chemical industries have been implemented in several countries such as the European Union, the United States, and Japan (Wang et al., 2012). The EU's legislations on chemical industries enacted in 1967 with the "Dangerous Substances Directive 67/548/EEC" regulates specific requirements for the classification, packaging and identification of hazardous materials. In Japan, the Chemical Substances Control Law (CSCL) was first established in 1974, and the latest amended legislation was published in 2009 for managing new industrial chemicals as well as the production, import and use based on the harmfulness of chemicals. The United States issued the Toxic Substances Control Act (TSCA) in 1976 to create a regulatory framework on chemical substances in order to evaluate, assess, mitigate, and control the industrial risks. In this study, the Seveso Directive was used to categorize industries based on a tiered approach of dangerous chemical quantities.

The Seveso Directive is the main component of the EU legislation that regulates technological hazards involving dangerous chemical substances. The "Seveso" accident that occurred in 1976 at a chemical plant in Seveso, Italy, prompted to the adoption of regulation aimed at the prevention of such accidents. The directive targets industrial establishments where dangerous substances are used or stored in large quantities, mainly in the chemicals, petrochemicals, storage, and metal refining sectors. In Europe, the Seveso Directive obligates EU Member States to formulate a policy related to the prevention of chemical accidents by ensuring emergency response plans, mitigation actions, as well as land-use planning. The tiered approach of dangerous chemical quantities control of Seveso I, Seveso II and Seveso III Directive were subsequently adopted and implemented in the EU Member States. Industrial establishments which have dangerous substances above certain thresholds set by the Directive must regularly inform the public likely to be affected, providing safety reports, a safety management system and an internal emergency plan.

The Seveso Directive evolved through the years to ensure better safety management for the industrial activities, as described below:

- **Seveso I**: *Council Directive 82/501/EEC on the major-accident hazards of certain industrial activities (OJ No L 230 of 5 August 1982)* was adopted in 1982. The Seveso Directive was amended twice, in 1987 by Directive 87/216/EEC of 19 March 1987 (OJ No L 85 of 28 March 1987) and in 1988 by Directive 88/610/EEC of 24 November 1988 (OJ No L 336 of 7 December 1988). The scope of the Directive was broadened with these two amendments, which included the storage of dangerous substances.
- **Seveso II**: *Council Directive 96/82/EC on the control of major-accident hazards* was adopted on 9 December 1996. The Seveso II Directive included a revision and extension of the scope; the introduction of new requirements related to safety management systems; emergency response and land-use planning; and reinforcement of the provisions for inspections.
- **Seveso III**: *Directive 2012/18/EU* was adopted on 4 July 2012 and entered into force on 13 August 2012. EU Member States have to transpose and implement the Directive by the June 1 2015. The Seveso III Directive takes into account the changes in EU chemical classification.

The recent Seveso Directive now has international classification and labeling standards for hazardous chemical substances, called the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). A regulation on the Classification, Labelling and Packaging (CLP) of substances and mixtures has been adapted to this new UN (United Nations) global system. The GHS is developed by the UN to standardize various classifications and labeling standards used in different countries by using uniform criteria on a global level. Countries can adopt whole or part of the GHS system into their own regulations, according to their specific requirements. The GHS has now been implemented in 67 countries as listed by the UNECE (2013). India has announced in January 2012 to issue rules governing the labeling of hazardous chemicals to align with the GHS (SSS, 2012). As for Bangladesh, there has been no report on the implementation of the GHS, however, it is important to enforce regulations in accordance with the GHS in the country given the extent of international trade in chemical industries.

A tiered approach has been implemented for the classification of dangerous chemical substances. The quantities of dangerous substances present within an industrial plant subject to the upper-tier and lower-tier establishment. The larger the quantities, the stricter the rules ("upper-tier" have larger quantities than "lower-tier", therefore apply to tighter control). The classification scheme based on the Seveso III Directive applied in this project was a follows:

- If the quantities of dangerous substances fell below the lower-tier threshold, the establishment was labeled as Acceptable.
- If the quantities of dangerous substances fell between the lower-tier and the upper-tier threshold, the establishment was labeled as Low.
- If the quantities of dangerous substances exceed the upper–tier threshold, the establishment was labeled as High.

1.4.2.2 ALOHA (Areal Locations of Hazardous Atmospheres)

A detailed assessment on dangerous chemical substances was conducted using ALOHA software on a specific chemical substance in each industrial plant. ALOHA is a chemical hazard modeling software jointly developed by the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA). It is designed as a tool to aid in emergency planning and response to chemical releases. Information about the physical properties of approximately 1,000 common hazardous chemicals is available in ALOHA.

ALOHA models three hazard categories related to chemical releases: toxic gas dispersion, fires, and explosions. ALOHA used air dispersion model to simulate the movement and dispersion of chemical gas clouds, then estimate the key hazards including toxicity, flammability, thermal radiation, or overpressure. The air dispersion model used in ALOHA (Gaussian or heavy gas) is designed to model the areas near a short-duration chemical release where key hazards may exceed user-specified Level of Concerns (LOCs). ALOHA employs additional models to estimate chemical releases associated with fires and explosions such as jet fires, pool fires, BLEVEs, flammable areas, and vapor cloud explosions. There are four types of sources: direct, puddle, tank, and gas pipeline that can be used to model chemical release in ALOHA. Each source may run different types of chemical hazard scenarios.

In general, there are several basic steps that typically perform to model chemical release using ALOHA:

1. Locate the city or area, including the date and time, where a chemical release occurred or simulated;
2. Select the chemical substances to be simulated from the ALOHA's chemical database;
3. Enter information about the atmospheric and weather conditions;
4. Provide detailed information on how the chemical is escaping from containment and scenarios to be considered; and

5. Display a threat zone plot using MARPLOT® or export to GIS systems, showing one or more areas where a hazard (toxic gas dispersion, flammable areas of a vapor cloud, thermal radiation, or overpressure from a vapor cloud explosion) may exceed the selected Levels of Concern (LOCs) and pose a threat to people and property.

The accuracy of ALOHA simulation greatly depends on how accurate the information is entered into the model. Unreliable results can be produced due to the following conditions: very low wind speeds, very stable atmospheric conditions, wind shifts and terrain steering effects, or concentration patchiness especially near the release source.

This methodology is applied on the data provided by ministry of Industries, Government of Bangladesh and results are presented below.

1.4.2.3 Results and Discussion

Classification based on the Seveso III Directive

A semi-qualitative analysis approach based on the Seveso III Directive was carried out to classify dangerous chemical substances present within the industrial area in Bangladesh. Data and information of BSFIC, BCIC, BSCIC, and BSEC industries were collected from the Ministry of Industries of the Government of Bangladesh. Available data required for the analysis included the name and location of industries, type of chemical substances present, and the amount or quantity stored in their storage. Out of 40 industries provided for the project, only 13 industries from BSFIC and BCIC were considered here due to lack of detailed data in other industries.

Lower- and upper-tiers of a dangerous substance were defined from the hazard categories of Annex I of the Seveso III Directive (Directive, 2012). Part 1 of the Annex is a generic threshold for substances with various hazardous properties according to H-phrases, while Part 2 covers an exception to these generic categories with threshold for specific dangerous substances. Hazard statement or H-phrases is a set of standardized phrases about the hazards of chemical substances and mixtures adapted to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Table 1.14 lists the classification of dangerous substances based on the Seveso III Directive for each industrial establishment.

Dangerous chemical substances present in the industries in Bangladesh are ammonia, lime, sulphur, sulphuric acid, phosphoric acid, hydrochloric acid, caustic soda, chlorine, soda ash, trisodium phosphate, calcium hypochloride, hydrogen peroxide, mercury, and barium carbonate. Among these substances, ammonium stored in many of the industries is classified as High Risk due to the large quantity of its chemical storage. Other high risk chemical substances are sulphur, sulphuric acid, phosphoric acid, and Trisodium Phosphate (TSP). Based on the Seveso III classification, high risk industries are Chittagong Urea Fertilizer Limited (CUFL), Jamuna Fertilizer Company (JFCL), Ashuganj Fertilizer and Chemical Company Limited (AFCLL), Urea Fertilizer Factory Limited (UFFL), Polash Fertilizer Factory Limited (PUFFL), Natural Gas

Fertilizer Factory Limited (NGFFL), DAP Fertilizer Company Limited (DAPFCL), and TSP Complex Limite (TSPCL). Meanwhile, Zeal Bangla Sugar Mills Ltd is a low risk industry.

The high prone areas to chemical hazards are located in Palash (Dhaka), Kotwali and Anwara (Chittagong), Brahmanbaria (Comilla), Fenchuganj and Chhatak (Sylhet), and Sarishabari (Jamalpur). Meanwhile, the low prone area is located in Baksiganj (Jamalpur).

Table 0.14: Classification of dangerous substances based on the Seveso III Directive

No	Name	Dangerous Substances	Quantity	Hazard Statement	Hazard Categories (Seveso Directive)	Lower-tier (tonnes)	Upper-tier (tonnes)	Hazard Classification
Bangladesh Sugar & Food Industries Corporation (BSFIC)								
1	Zeal Bangla Sugar Mills Ltd.	Lime (CaO)	50 MT	H315, H318, H335	PART 1 - H3	50	200	Low
		Sulphur	70 MT	H315	PART 1 - H3	50	200	Low
		Fertilizer	500 MT	-	-	-	-	-
Bangladesh Chemical Industries Corporation (BCIC)								
1	Chittagong Urea Fertilizer Limited (CUFL)	Ammonia	5,000 MT	H221, H280, H331, H314, H400	PART 2	50	200	High
		Urea	Bulk: 85,000 MT; Bagged: 15,000 MT; RCC: 7,000 MT	-	-	-	-	-
		Sulphuric Acid	-	H314	PART 1 - H3	50	200	-
		Caustic soda (NaOH)	-	H314	PART 1 - H3	50	200	-
		Chlorine	-	H270, H280, H315, H319, H331, H335, H400	PART 2	10	25	-
2	Jamuna Fertilizer Company (JFCL)	Ammonia (Liquid)	10,000 MT	H221, H280, H331,	PART 2	50	200	High

No	Name	Dangerous Substances	Quantity	Hazard Statement	Hazard Categories (Seveso Directive)	Lower-tier (tonnes)	Upper-tier (tonnes)	Hazard Classification
				H314, H400				
		Urea	Bulk: 50,000 MT; Bagged: 14,000 MT	-	-	-	-	-
		Sulphuric Acid (H_2SO4)		H314	PART 1 - H3	50	200	-
		Caustic soda (NaOH)		H314	PART 1 - H3	50	200	-
		Soda Ash (Na_2CO_3)		H319	PART 1 - H3	50	200	-
		Chlorine		H270, H280, H315, H319, H331, H335, H400	PART 2	10	25	-
3	Ashuganj Fertilizer & Chemical Company Limited (AFCLL)	Ammonia (Liquid)	10,000 MT	H221, H280, H331, H314, H400	PART 2	50	200	High
		Urea	Urea: 40,000 MT; Bagged: 22,500 MT	-	-	-	-	-
		Sulphuric Acid	102 MT	H314	PART 1 - H3	50	200	Low
		Caustic soda (NaOH)	13 MT	H314	PART 1 - H3	50	200	Acceptable

No	Name	Dangerous Substances	Quantity	Hazard Statement	Hazard Categories (Seveso Directive)	Lower-tier (tonnes)	Upper-tier (tonnes)	Hazard Classification
		Chlorine	4 MT	H270, H280, H315, H319, H331, H335, H400	PART 2	10	25	Acceptable
4	Urea Fertilizer Factory Limited (UFFL)	Ammonia	1,500 MT	H221, H280, H331, H314, H400	PART 2	50	200	High
5	Polash Fertilizer Factory Limited (PUFFL)	Ammonia (Liquid)	1,000 MT	H221, H280, H331, H314, H400	PART 2	50	200	High
		Urea	Loose: 1,525 MT; Bagged: 12,200 MT	-	-	-	-	-
6	Natural Gas Fertilizer Factory Limited (NGFFL)	Ammonia	1,000 MT	H221, H280, H331, H314, H400	PART 2	50	200	High
		Urea	33,500 MT	-	-	-	-	-
		Sulphuric Acid (H_2SO4)	400 MT	H314	PART 1 - H3	50	200	High

No	Name	Dangerous Substances	Quantity	Hazard Statement	Hazard Categories (Seveso Directive)	Lower-tier (tonnes)	Upper-tier (tonnes)	Hazard Classification
		Ammonium Sulphate	2,500 MT	-	-	-	-	-
7	TSP Complex Ltd. (TSPCL)	Rock Phosphate	67,000 MT	-	-	-	-	-
		Rock Sulphur	2,300 MT	H315	PART 1 - H3	50	200	High
		Phosphoric Acid	10,000 MT	H290, H314	PART 1 - H3	50	200	High
		Sulphuric Acid (H_2SO4)	8,000 MT	H314	PART 1 - H3	50	200	High
		Trisodium phosphate (TSP)	25,000 MT	H315, H318, H335	PART 1 - H3	50	200	High
8	DAP Fertilizer Company Limited (DAPFCL)	Phosphoric Acid	64,000 MT	H290, H314	PART 1 - H3	50	200	High
		Sulphuric Acid (H_2SO4)	900 MT	H314	PART 1 - H3	50	200	High

No	Name	Dangerous Substances	Quantity	Hazard Statement	Hazard Categories (Seveso Directive)	Lower-tier (tonnes)	Upper-tier (tonnes)	Hazard Classification
		Ammonia (Liquid)	6,000 MT	H221, H280, H331, H314, H400	PART 2	50	200	High
		Di-Ammonium Phosphate	Bulk: 60,000 MT; Bagged: 20,000 MT	-	-	-	-	-
9	Karnaphuli Paper Mills Ltd. (KPM)	Chlorine		H270, H280, H315, H319, H331,	PART 2	10	25	-
				H335, H400				
		Caustic soda (NaOH)		H314	PART 1 - H3	50	200	-
		Hydrochloric Acid (HCI)		H314	PART 1 - H3	50	200	-
		Calcium Hypochloride (Ca(OCl))		H271, H314, H302, H400	PART 1 - P8	50	200	-
		Lime (CaO)		H315, H318, H335	PART 1 - H3	50	200	-

No	Name	Dangerous Substances	Quantity	Hazard Statement	Hazard Categories (Seveso Directive)	Lower-tier (tonnes)	Upper-tier (tonnes)	Hazard Classification
		Sulphuric Acid (H_2SO4)	Bulk: 20,000 MT	H314	PART 1 - H3	50	200	-
		Magnesium Sulphate (MgSO4)		-	-	-	-	-
		Hydrogen Peroxide (H_2O_2)		H271, H302, H314, H332	PART 1 - P8	50	200	-
		Sodium Sulphate (Na_2SO_4)		-	-	-	-	-
		Mercury (Hg)		H301, H319, H315	PART 1 - H2	50	200	-
		Alkylketene Dimer (AKD)		-	-	-	-	-
10	Chhatak Cement Company Ltd. (CCCL)	Lime stone	55,000 MT	H315, H318, H335	PART 1 - H3	50	200	High
		Clay	2,000 MT	-	-	-	-	-

No	Name	Dangerous Substances	Quantity	Hazard Statement	Hazard Categories (Seveso Directive)	Lower-tier (tonnes)	Upper-tier (tonnes)	Hazard Classification
		Gypsum	2,000 MT	-	-	-	-	-
		Clinker	15,000 MT	-	-	-	-	-
		Cement	15,000 MT	-	-	-	-	-
11	Bangladesh Insulator & Sanitary Ware Factory Ltd. (BISF)	Bauxite	-	-	-	-	-	-
		Sodium Silicate	-	H314, H335	PART 1 - H3	-	-	-
		Zirconiam Silicate	-	-	-	-	-	-
		Zinc oxide	-	H410	PART 1 - E1	-	-	-
		Barium Carbonate	-	H302	PART 1 - H2	50	200	-

No	Name	Dangerous Substances	Quantity	Hazard Statement	Hazard Categories (Seveso Directive)	Lower-tier (tonnes)	Upper-tier (tonnes)	Hazard Classification
		Talcom Powder	-	-	-	-	-	-
		Soda Ash	-	H319	PART 1 - H3	50	200	-
		Dolomite	-	-	-	-	-	-
12	Usmania Glass Sheet Factory Ltd. (UGSF)	Soda Ash		H319	PART 1 - H3	50	200	-
		Dolomite Powder	Two godown: 2,000 MT	-	-	-	-	-
		Sodium Sulphate (Na_2SO_4)		-	-	-	-	-

Source: Ministry of Industries, 2013

Hazard Statement

H221 - Flammable gas

H270 - May cause or intensify fire; oxidiser

H271 - May cause fire or explosion; strong oxidizer

H280 - Contains gas under pressure, may explode if heated

H290 - May be corrosive to metals

H301 - Toxic if swallowed

H302 - Harmful if swallowed

H314 - Causes severe skin burns and eye damage

H315 - Causes skin irritation

H318 - Causes serious eye damage

H319 - Causes serious eye irritation

H331 - Toxic if inhaled

H332 - Harmful if inhaled

H335 - May cause respiratory irritation

H400 - Very toxic to aquatic life

H410 - Very toxic to aquatic life with long lasting effects

Hazard Categories (Seveso Directive)

PART 1 -

H2: Acute Toxic

H3: Specific Target Organ Toxicity - Single Exposure

P8: Oxidising Liquids and Solids

E1: Hazardous to the aquatic environment

PART 2 - Named dangerous substances in Category Acute 1 or Chronic 1

1.4.2.4 Simulation of Chemical Hazard using ALOHA

Chemical hazard modeling was conducted using ALOHA for the industries that have dangerous chemical substances classified as high tisk according to the Seveso III Directive. High risk chemical substances such as ammonia, sulphur, sulphuric acid, phosphoric acid, and Trisodium Phosphate (TSP) were identified in several industries in Bangladesh (Table 1.14). However, the only hazardous chemical that meets ALOHA's standards for chemical hazard modeling is ammonia. Therefore, the only chemical substance modeled in this study was ammonia. The air dispersion hazard model used by ALOHA requires certain physical properties of a chemical substance to be considered hazardous to the environment or people within a large area. Information about the physical properties of hazardous substances is available in CAMEO Chemicals library. CAMEO reports that the vapor pressure of ammonia is 400 mm Hg at -49.72°F, sulphuric acid is 1 mm Hg at 294.8°F, and phosphoric acid is 0.03 mm Hg. Meanwhile, physical properties of sulphur and TSP are not available. Ammonia shows a much higher vapor pressure, while others display a very low vapor pressure that are not volatile enough to be considered an outdoor air dispersion on chemical hazard.

ALOHA 5.4.4 was used to simulate the ammonia releases from a leaking tank in industrial sites of Bangladesh. Polash Fertilizer Factory Limited (PFFL) in Dhaka city was taken to illustrate the chemical hazard simulation. The plant stored 1,000 MT of ammonia, which according to the Seveso III Directive classified as high risk. Ammonia is identified as toxic, corrosive and dangerous for the environment. The site specific information was entered into the model concerning the location of the plant, the meteorological and atmospheric information, the type and volume of the chemical component, the physical characteristic of the containment, the hazard scenario, and the type of spill.

The maximum temperature recorded in Dhaka station (2005-2007) was 38.5°C. The wind direction assumed from the west at maximum speed of 15 knots. The sky is assumed to be half covered by clouds with the humidity of about 75 percent. The ALOHA estimated stability class is D. There is no low-level inversion. The industrial park is located in an open area with a few buildings and large paddy fields.

The simulation considered ammonia leaking from a tank with the following specifications. The tank assumed to have a vertical cylinder shape, with a volume capacity of 1.75 million liters and a diameter of 15m. The ammonia is stored in the tank as a liquid (boiling point of -33.4°C). The mass in the tank is 1,000 MT, which is almost 90 percent of the full capacity of the tank. The ammonia is leaking from a 1.5 inch circular hole located 1m above the bottom of the tank, but the chemical is not burning as it escapes into the atmosphere. The size of the circular hole significantly affects the model results, thus three other opening diameter values were considered: 1, 2, and 2.5 inches.

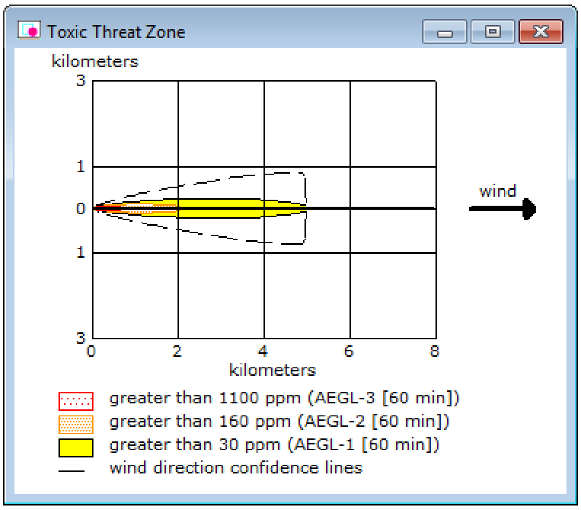
The ALOHA model estimated the duration of the release, maximum average of release rate, and total amount of the chemical released. Three classes were defined based on the selected LOC (Level of Concern), according to the Acute Exposure Guideline Levels (AEGL). AEGLs are the guidelines of exposure developed for emergencies involving chemical spills or other catastrophic events where the people are exposed to a hazardous airborne chemical. A summary of the results is given in Table 1.15.

From Table 1.15, it can be seen that the rate and total amount of chemical releases increased when the diameter of the opening become larger. The information on duration is limited up to one hour, so that a release beyond an hour is not specified. Threat zone or LOC also shows similar behavior, the larger the opening diameter, the greater the distance of the ammonia releases. The maximum distance that the ALOHA can model is up to 10 km. Any scenario that results in an endpoint distance beyond 10 km is defined as "greater than 10 kilometers", as in the case of AEGL-3 for the opening of 2.0 and 2.5 inches.

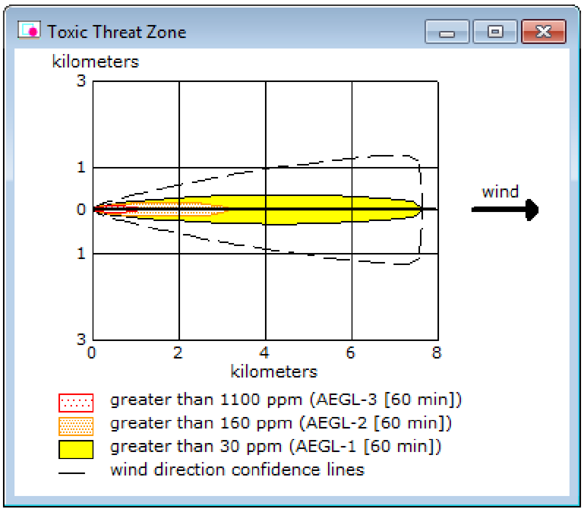
Table 0.15: Model prediction of the ammonia releases and threat zone

Opening diameter (inch)	Chemical releases			Threat Zone or LOC (Km)		
	Duration (Hour)	Release rate (Kg/min)	Total amount (Kg)	AEGL-1 1100 ppm	AEGL-2 160 ppm	AEGL-3 30 ppm
1	> 1	0.756	45.275	0.733	2.1	5.0
1.5	> 1	1.700	101.621	1.1	3.2	7.7
2	> 1	3.020	180.020	1.5	4.3	> 10.0
2.5	> 1	4.710	279.928	1.9	5.4	> 10.0

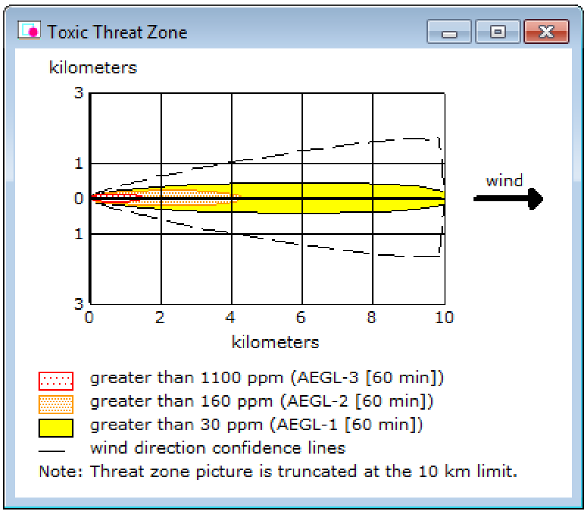
Figure 1.37 shows ALOHA's toxic threat zone for scenarios of different opening diameter. AEGLs estimate the concentration level (expressed as parts per million – ppm) at which a specific duration of exposure to a hazardous airborne chemical substance begin to affect peoples' health. AEGL-3 indicates life-threatening health effects or death to nearly all individuals. AEGL-2 indicates serious health effects or impairs an individual's ability to escape or take protective action. AEGL-1 indicates notable discomfort or irritation effects that are not disabling and can be reversible. The ALOHA graphic always displays downwind direction to the right, however, it is not an indication of the true wind directions.



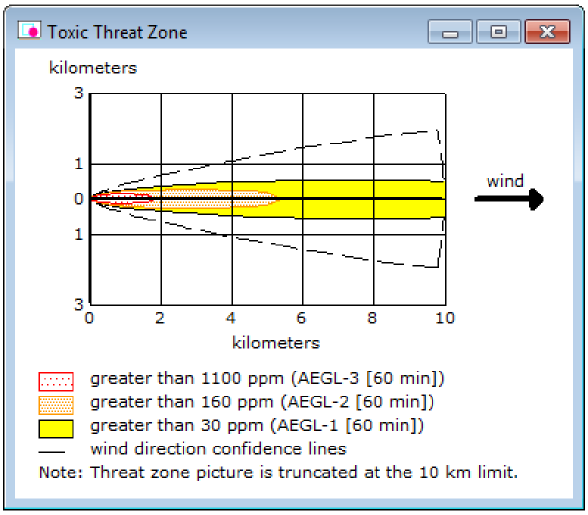
(a) Opening diameter = 1 inch



(b) Opening diameter = 1.5 inches



(c) Opening diameter = 2 inches



(d) Opening diameter = 2.5 inches

Figure 0.37: Toxic threat zone for different diameter of opening: 1, 1.5, 2, and 2.5 inches

The visualization of the ammonia threat zone of Polash Fertilizer Factory Limited (PFFL) is displayed with GIS software (Figure 1.38). A base map from Open Street Map is overlaid with the toxic threat zone of the leaking ammonia tank with 1.5 inches opening diameter to show the extent and severity of the chemical hazard. The wind direction is considered to be all-around so that the extent of ammonia release shows a circular threat zone instead of one single direction.

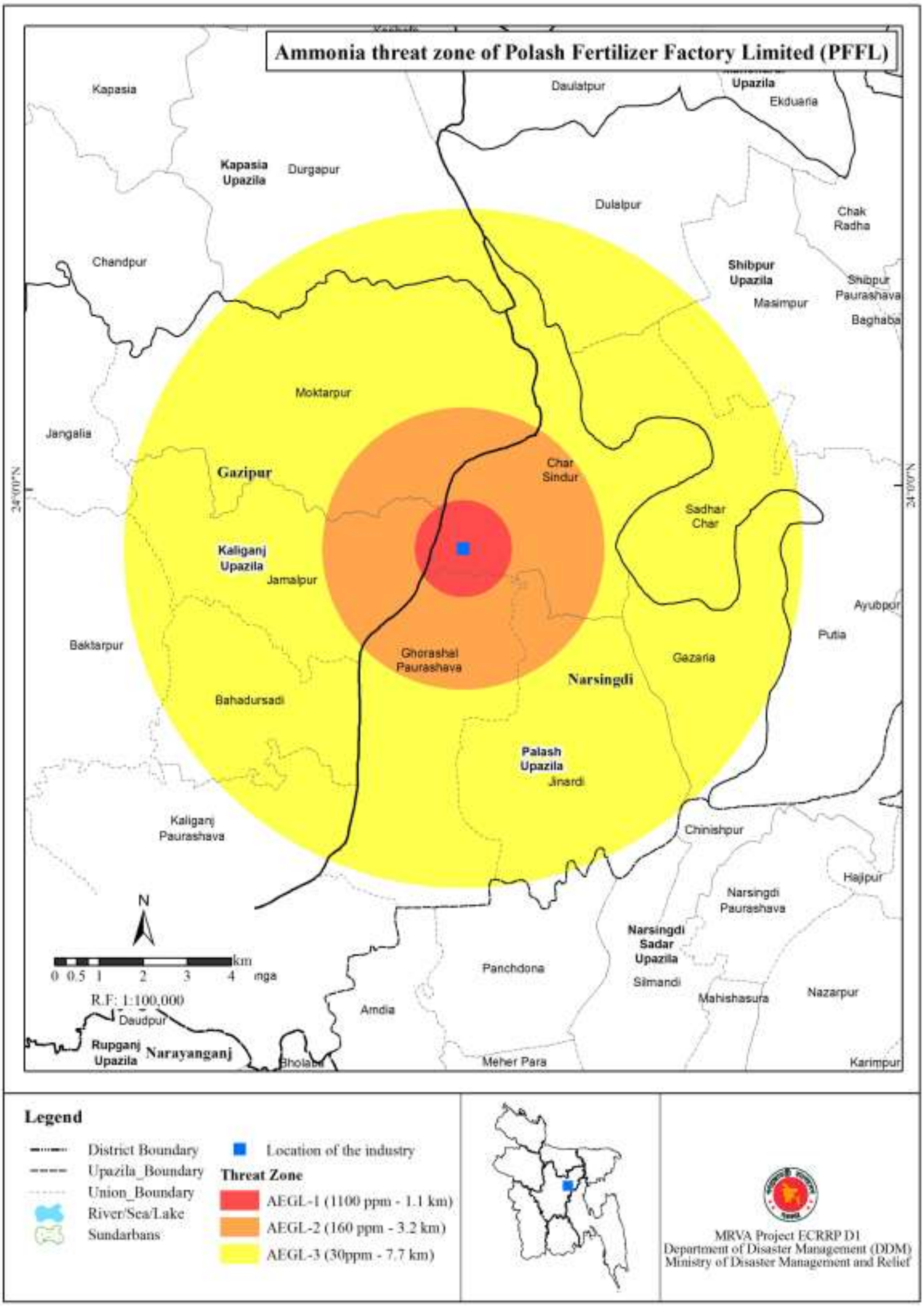


Figure 0.38: Ammonia threat zone of Polash Fertilizer Factory Limited (PFFL)

Ammonia is also present in several chemical industries in Bangladesh such as Ashuganj Fertilizer and Chemical Company Factory Limited (AFCCL), Chittagong Urea Fertilizer Ltd.

(CUFL), DAP Fertilizer Company Ltd. (DAPFCL), Jamuna Fertilizer Company Ltd. (JPFCL), and Natural Gas Fertilizer Factory Ltd. (NGFFL) (Table 1.14). A simulation of ammonia releases from a leaking tank was carried out for other chemical industries and the model parameters and assumption used in this study is shown in Table 1.16. The meteorological parameter values were taken from the closest meteorological station from the industry.

Table 0.16: The model parameters and assumption used for the simulation of ammonia release

Name of industry	Meteorological parameters		Container (assumption)		Quantity of ammonia storage (MT)	Area of leaking (assumption)	
	Max average temp. (°C)	Max wind speed (Knots)	Tank diameter (m)	Tank volume (L)		Circular opening diameter (inches)	Opening location above the bottom (m)
AFCCL	38.5	15	30	17,000,000	10,000	1.5	1
CUFL	38.4	18	25	8,500,000	5,000	1.5	1
DAPFCL	38.4	18	25	10,500,000	6,000	1.5	1
JFCL	40.5	15	30	17,000,000	10,000	1.5	1
NGFFL	38	17	15	1,750,000	1,000	1.5	1

The model prediction of ammonia releases and the threat zone based on the AEGL guidelines is shown in Table 1.17. The toxic endpoints reach up to almost 8 km for AEGL-3 with the total release amount of more than 100 thousand kilograms. Figures 1.39, 1.40, 1.41, 1.42 and 1.43 show the map of the ammonia threat zone of AFCCL, CUFL, DAPFCL, JPFCL, NGFFL, respectively.

Table 0.17: Model prediction of the ammonia releases and threat zone for other chemical industries

Name of industry	Chemical releases			Threat Zone or LOC (Km)		
	Duration (Hour)	Release rate (Kg/min)	Total amount (Kg)	AEGL-1 1100 ppm	AEGL-2 160 ppm	AEGL-3 30 ppm
AFCCL	> 1	1.740	104.667	1.1	3.2	7.8
CUFL	> 1	1.720	103.256	1.0	2.9	7.0
DAPFCL	> 1	1.730	103.906	1.0	2.9	7.0
JFCL	> 1	1.790	107.287	1.2	3.3	7.9
NGFFL	> 1	1.690	100.954	1.1	3.0	7.2

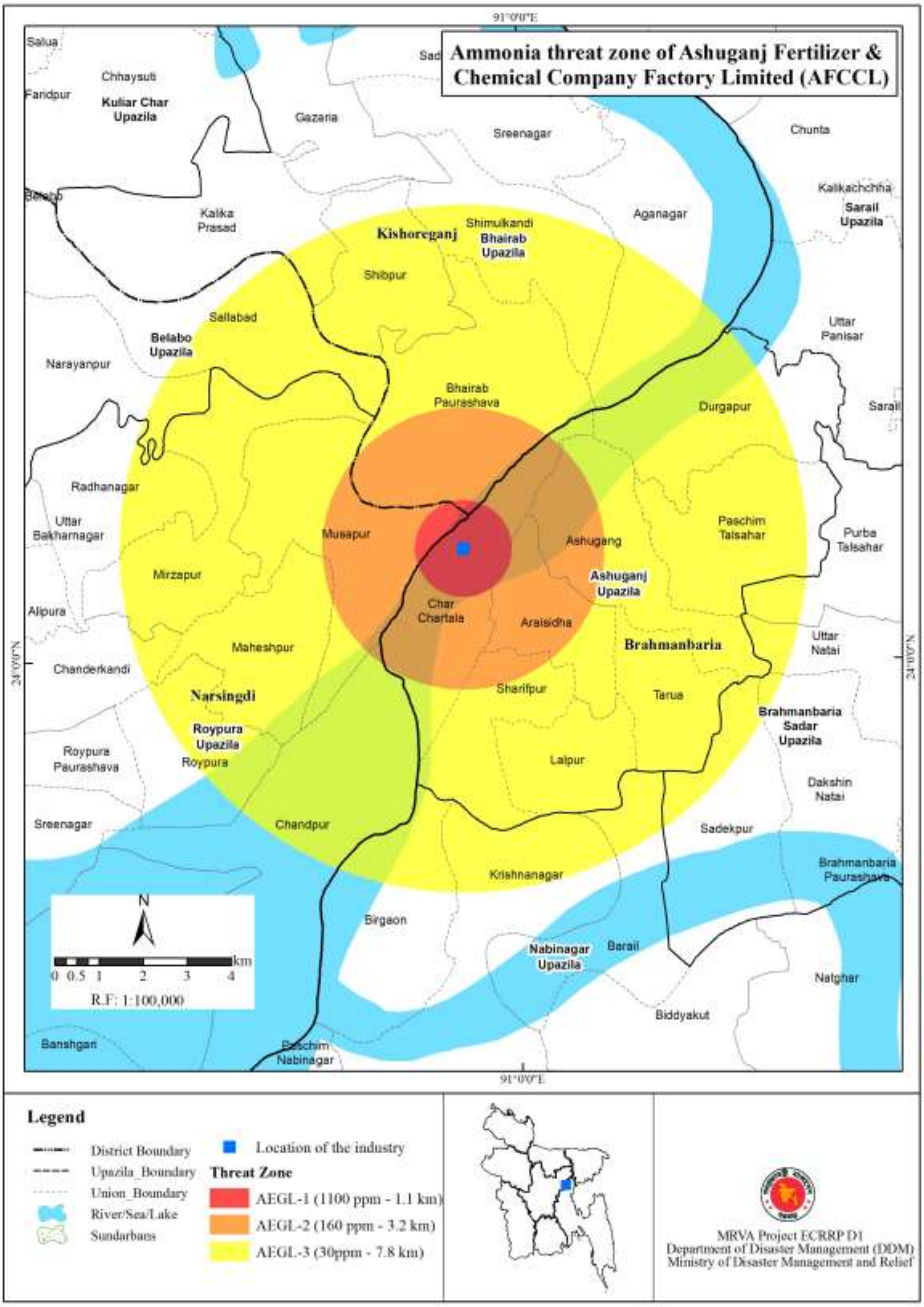


Figure 0.39: Ammonia threat zone of Ashuganj Fertilizer and Chemical Company Factory Limited (AFCCL)

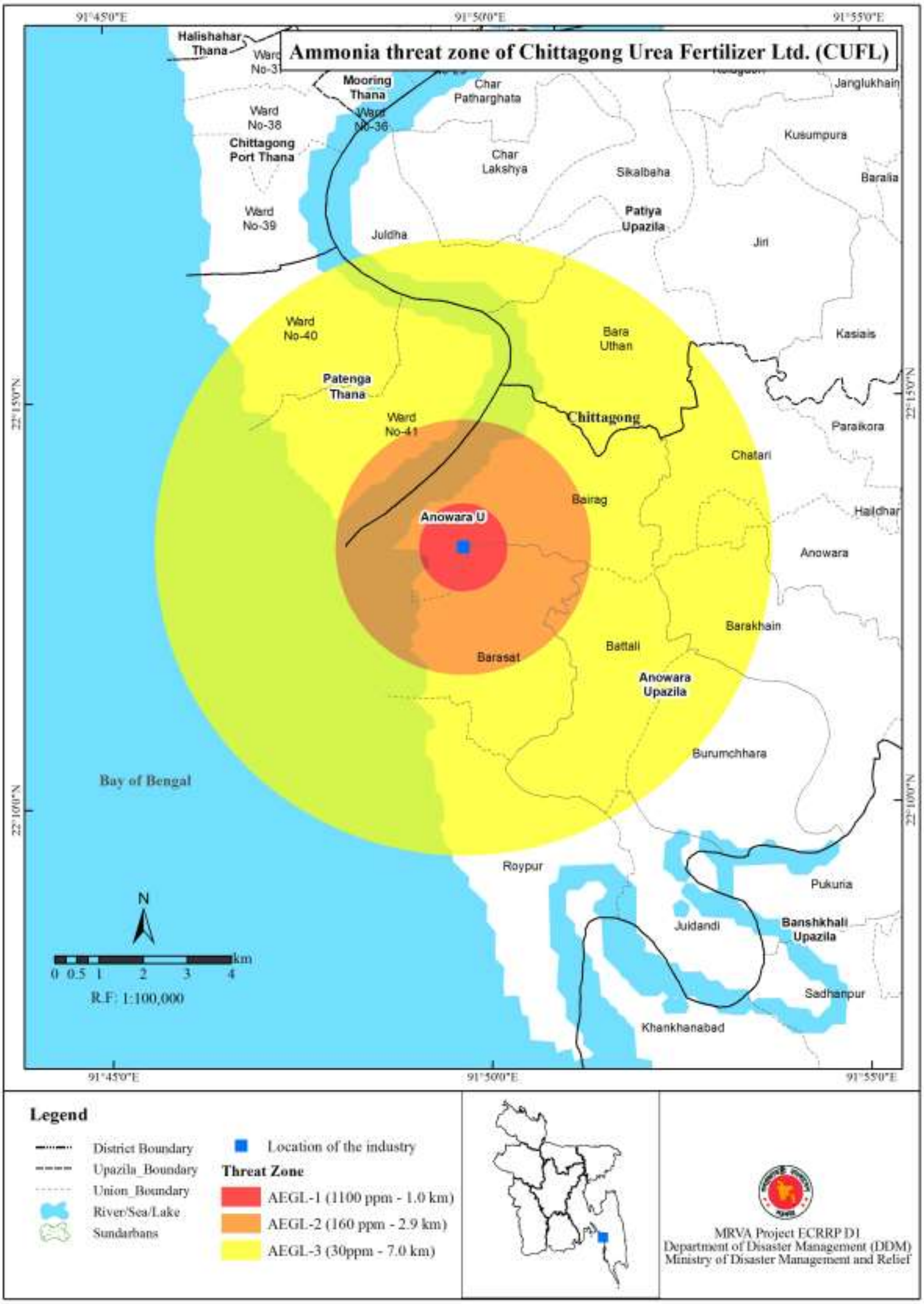


Figure 0.40: Ammonia threat zone of Chittagong Urea Fertilizer Ltd. (CUFL)

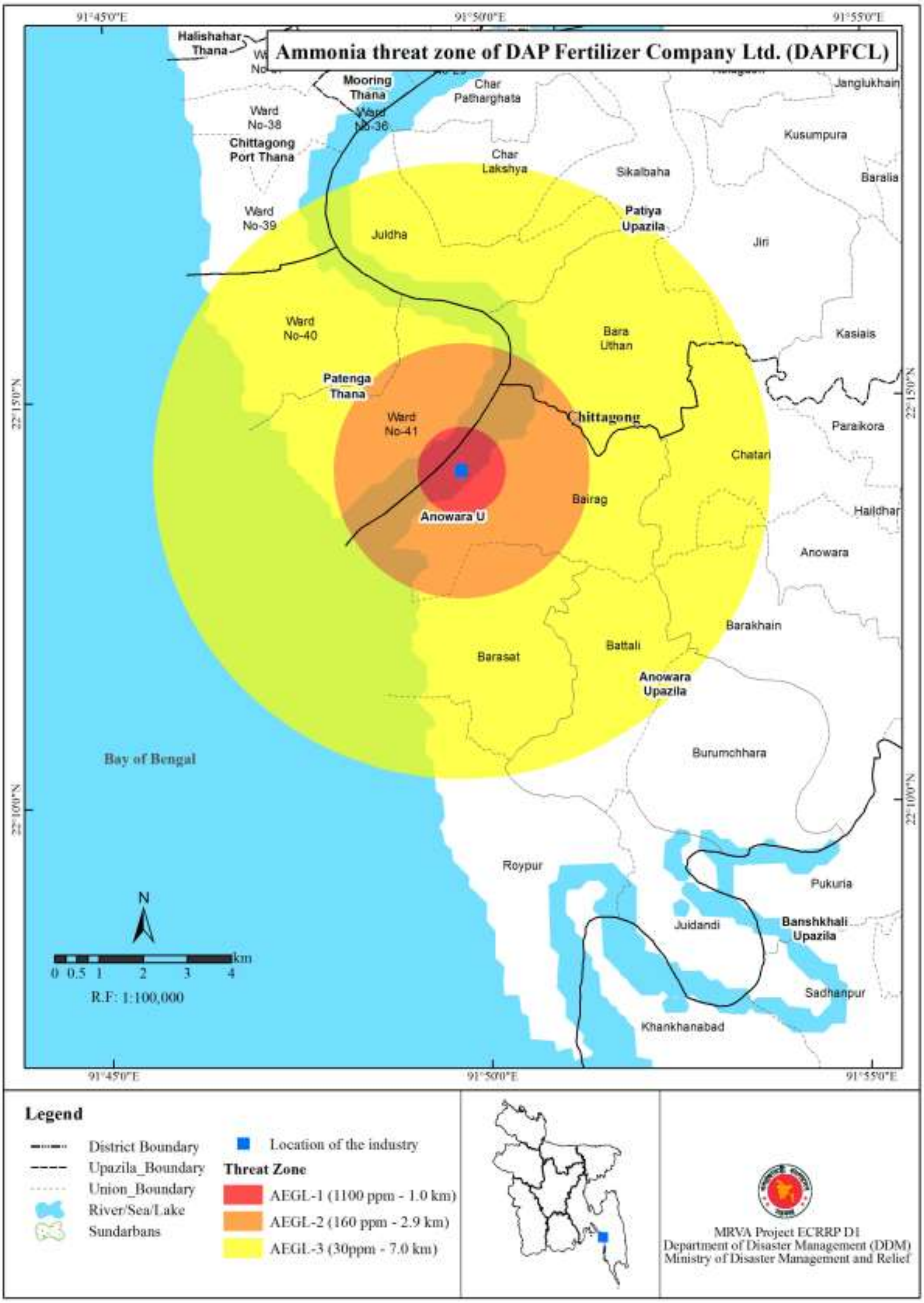


Figure 0.41: Ammonia threat zone of DAP Fertilizer Company Ltd. (DAPFCL)

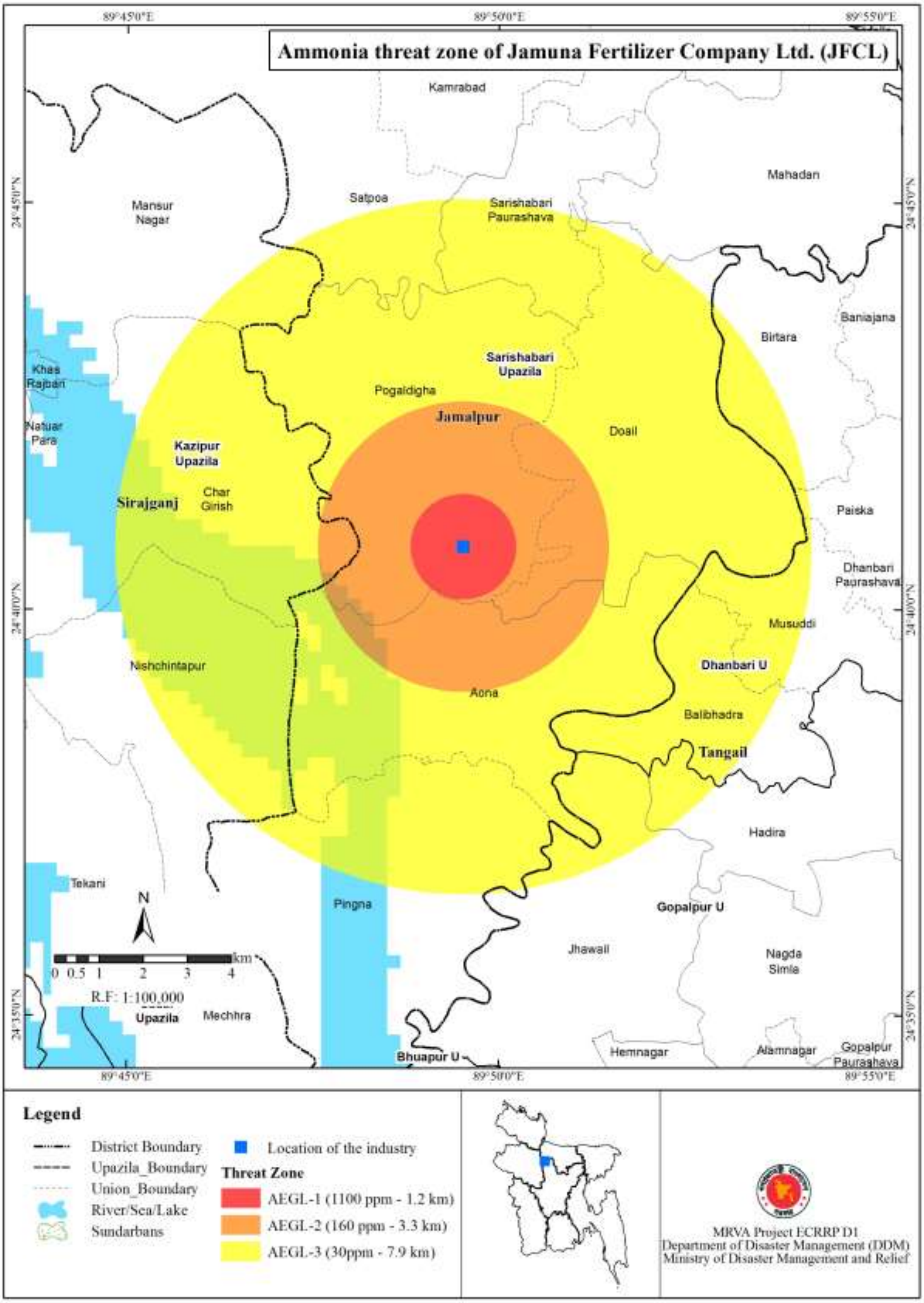


Figure 0.42: Ammonia threat zone of Jamuna Fertilizer Company Ltd. (JFCL)

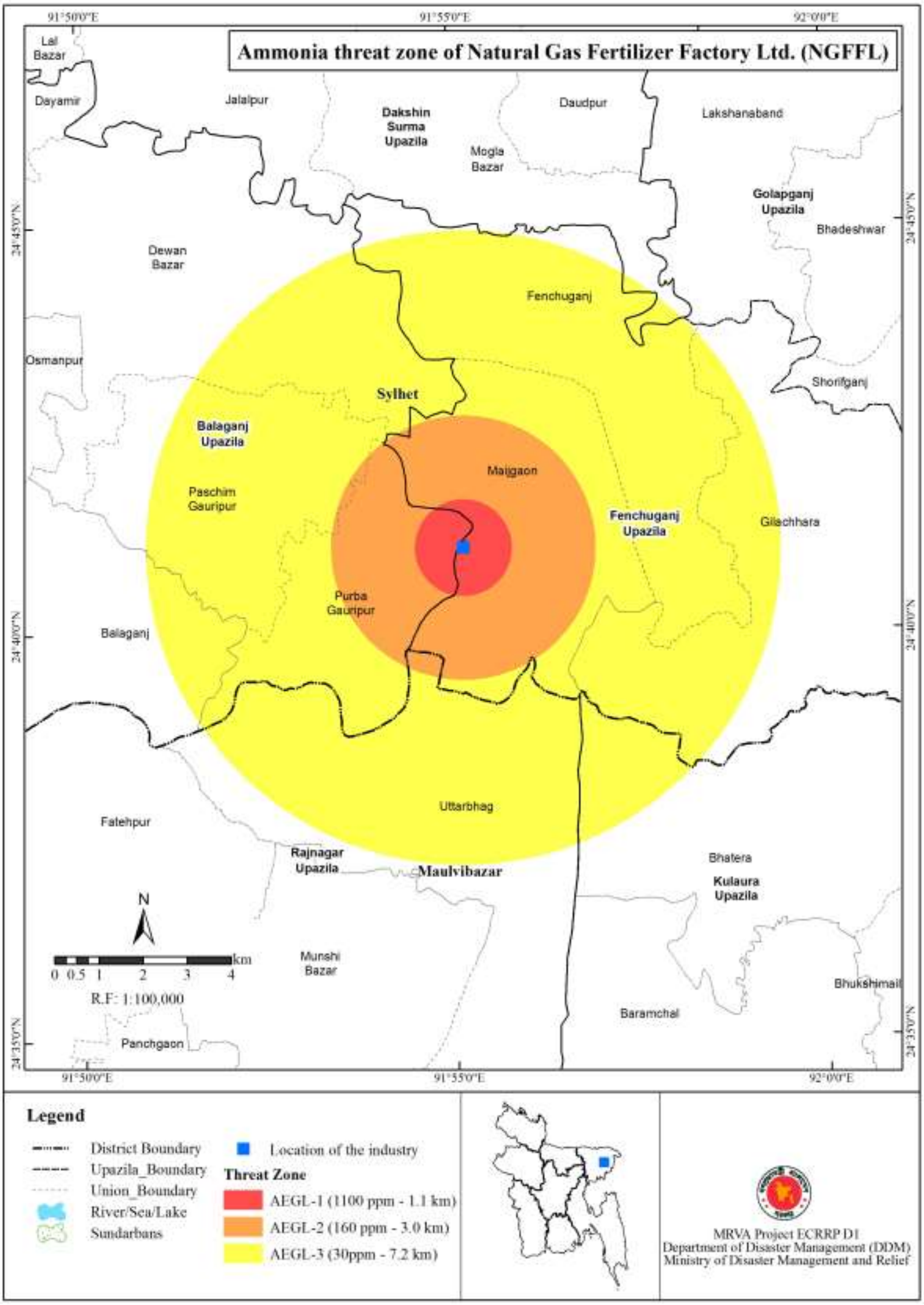


Figure 0.43: Ammonia threat zone of Natural Gas Fertilizer Factory Ltd. (NGFFL)

1.4.3 Analysis of Hazard Assessment

The simulation of possible leakage of ammonia using ALOHA methodology in the six out of seven chemical industries are mentioned in Table 1.15 (page 71 to 80). The hazard zones of each industry are combined with union/upazila/district maps to assess the area (km^2) and percentage of area affected in each union, upazila and district. The summary of the extent of possible area and percentage affected for each industry is given in Table 1.18.

Table 0.18: Possible affected area and percentage in each union/upazila/district due to each industry

Sl. No.	Name of the Industry	Hazard Zone / Length of influence	Geographical area affected			
			District	Upazillas	Union (% of area)	Area (sq.km)
1	Ashuganj Fertilizer & Chemical Company Factory Limited (AFCCL)	AEGL- 1 (1100 ppm) / 1.1 km	Brahmanbaria	Ashuganj	Araisidha (0.15%)	0.01
					Char Chartala (5.62%)	0.6
		AEGL- 2 (160 ppm) / 3.2 km	Brahmanbaria	Ashuganj	Araisidha (44.76%)	2.98
					Ashugang (30.72%)	3.38
					Char Chartala (47.19%)	5
			Kishoreganj	Bhairab Upazila	Bhairab Paurashava (17.05%)	3.1
			Narsingdi	Roypura Upazila	Musapur (26.34%)	3.96
		AEGL- 3 (30 ppm) / 7.8 km	Brahmanbaria	Ashuganj, Brahmanbaria Sadar Upazila, Nabinagar Upazila	many unions	varying from 3.66 to 23.65
			Kishoreganj	Bhairab Upazila	many unions	varying from 8.94 to 15.06
			Narsingdi	Belabo Upazila, Roypura Upazila	many unions	varying from 8.82 to 26.37
2	Chittagong Urea Fertilizer Ltd.	AEGL- 1 (1100 ppm) / 1.0 km	Chittagong	Anowara Upazila, Patiya Upazila	NIL	NIL (No settlement)

Sl. No.	Name of the Industry	Hazard Zone / Length of influence	Geographical area affected			
			District	Upazillas	Union (% of area)	Area (sq.km)
	(CUFL)	AEGL- 2 (160 ppm) / 2.9 km	Chittagong	Anowara Upazila	Bairag (28.94%)	5.35
					Barasat (31.25%)	4.29
					Battali (5.68%)	0.67
		AEGL- 3 (30 ppm) / 7.0 km	Chittagong	Anowara Upazila, Patiya Upazila	many unions	varying from 8.21 to 22.94
3	DAP Fertilizer Company Ltd. (DAPFCL)	AEGL- 1 (1100 ppm) / 1.0 km	Chittagong	Anowara Upazila, Patiya Upazila	NIL	NIL (No settlement)
		AEGL- 2 (160 ppm) / 2.9 km	Chittagong	Anowara Upazila	Bairag (22.35%)	4.13
					Barasat (1.93%)	0.26
				Patiya Upazila	Bara Uthan (5.85%)	0.92
		AEGL- 3 (30 ppm) / 7.0 km	Chittagong	Anowara Upazila, Patiya Upazila	many unions	varying from 8.21 to 22.94
4	Jamuna Fertilizer Company Ltd. (JFCL)	AEGL- 1 (1100 ppm) / 1.2 km	Jamalpur	Sarishabari Upazila	Pogaldigha (0.57%)	0.22
		AEGL- 2 (160 ppm) / 3.3 km	Jamalpur	Sarishabari Upazila	Aona (1.17%)	0.37
					Doail (9.87%)	3.29
					Pogaldigha (10.26%)	4
		AEGL- 3 (30 ppm) / 7.9 km	Jamalpur	Sarishabari Upazila	many unions	varying from 13.29 to 40.40
			Tangail	Dhanbari Upazila, Gopalpur Upazila	many unions	varying from 10.62 to 27.91
			Sirajganj	Kazipur upazila	Char Girish (100%)	38.07
5	Natural Gas Fertilizer	AEGL- 1 (1100 ppm) / 1.1 km	Sylhet	Balaganj Upazila	Purba Gauripur (12.16%)	2.22

Sl. No.	Name of the Industry	Hazard Zone / Length of influence	Geographical area affected			
			District	**Upazillas**	**Union (% of area)**	**Area (sq.km)**
	Factory Ltd. (NGFFL)			Fenchyganj Upazila	Maijgaon (2.90%)	0.85
		AEGL- 2 (160 ppm) / 3.0 km	Maulvibazar	Rajnagar Upazila	Uttarbhag (1.02%)	0.55
			Sylhet	Balaganj Upazila	Purba Gauripur (21.65%)	3.95
				Fenchyganj Upazila	Maijgaon (41.19%)	12.06
		AEGL- 3 (30 ppm) / 7.2 km	Maulvibazar	Kulaura Upazila	Bhatera (100%)	38.73
				Rajnagar Upazila	Uttarbhag (98.98%)	52.84
			Sylhet	Balaganj Upazila, Fenchuganj Upazila	many unions	varying from 12.07 to 51.35
6	Polash Fertilizer Factory Limited (PFFL)	AEGL- 1 (1100 ppm) / 1.1 km	Gazipur	Kaliganj Upazila	Jamalpur (4.07%)	0.81
					Moktarpur (0.43%)	0.17
			Narsigdi	Palash Upazila	Char Sindur (7.29%)	1.47
					Ghorashal Paurashava (0.58%)	0.13
		AEGL- 2 (160 ppm) / 3.2 km	Gazipur	Kaliganj Upazila	Jamalpur (24.56%)	4.89
					Moktarpur (17.35%)	6.71
			Narsingdi	Palash Upazila	Char Sindur (32.18%)	6.51
					Ghorashal Paurashava (28.91%)	6.36
					Jinardi (6.41%)	1.51
		AEGL- 3 (30 ppm) / 7.7 km	Gazipur	Kaliganj Upazila, Kapasia Upazila	many unions	varying from 13.99 to 37.41

Sl. No.	Name of the Industry	Hazard Zone / Length of influence	Geographical area affected			
			District	Upazillas	Union (% of area)	Area (sq.km)
			Narsingdi	Narsingdi Sadar Upazila, Palash Upazila, Shibpur Upazila	many unions	varying from 12.25 to 25.99

1.4.4 Map Content

The hazards maps of ammonia leakage from selected industries represents different levels of concentration of ammonia pollution in parts per million (ppm). The concentration has been categorized into three levels, which are Acute Exposure Guideline Levels (AEGL). The length of the influence of these pollution zones varies based on the diameter of the opening in the tank in which ammonia is stored and details are given in Table 1.15. The color codes used for these three pollution levels are given in Table 1.19.

Table 0.19: Classification of Ammonia pollution levels in Chemical industries (Technological hazards)

Level of Ammonia pollution (in ppm)	Acute Exposure Guideline Levels (AEGL)	Hazard Level	Color code
1100 ppm	AEGL- 1	Very High	
160 ppm	AEGL- 2	High	
30 ppm	AEGL- 3	Moderate	

1.4.5 Application of Maps

- Using the hazard maps of each industry, the area and length of influence due to different levels of pollution due to ammonia release can be assessed.
- These maps can be used for communicating early warning to the population living in most dangerous zones nearby these factories.
- The impact of chemical (ammonia) hazard on human and environment is to be monitored on a regular basis to prevent any damage to crops and livestock.

1.4.6 Special Remarks

Impacts of Chemical Hazards on Humans and Environment

Chemical industries in Bangladesh mainly stored and used ammonia as fertilizers. Ammonia is generally stored in tanks as liquefied under pressure. It becomes a toxic gas when released into the air and it has the potential for harmful effects on both the human health and environment. Exposure to people is the main concern of chemical hazard due to ammonia releases. Effects of ammonia inhalation range from irritation to severe respiratory injuries, with possible fatality at higher concentrations (EPA, 2001). In the presence of a river or other water bodies, ammonia may lead to eutrophication of surface waters, causing excessive plant growth and decay, severe reductions in water quality, and endangered fish or other aquatic life. Changes in ecosystem, fertilization of vegetation, and soil acidification are another threat of ammonia for the environment.

Concluding Remarks

The spatial distribution of the chemical-based industries shows that Dhaka and Chittagong are the center of industry in Bangladesh. These two cities account for more than half of the total industries in Bangladesh. With the rapid increase of industrialization in Bangladesh during the last few decades, this country is prone chemical disasters. According to the FACTS database, there were at least twenty-nine accidents involving chemical materials in Bangladesh from 1974 to 2008.

Chemical hazard identification and assessments have been prepared in this study through a semi-qualitative analysis approach based on the Seveso III Directive and a simulation of chemical release on a particular industrial establishment using ALOHA. Among dangerous substances present in Bangladesh industries, ammonium stored in many of the establishments and it is classified as high risk due to high quantity of its chemical storage. A simulation of ammonia releases from a leaking tank were carried out for six chemical industries in Bangladesh. The toxic endpoints reach up to almost 8 km with a total release amount of more than 100 thousand kilograms. A detailed and accurate information on specific plant or industrial facilities is critical to ensure the accuracy of the results. The completeness of information about industries available for this study is vary widely from site to site, thus limits the use of hazard modeling.

1.4.7 Recommendations

- This study has been carried out using only data of few industries, for which data was provided by ministry of industries. However, the same methodology can be adopted in other industries for which data will be available.
- Since wind speed is most dynamic, it was not considered for assessment hazard zones. Based on the wind speed on monthly basis, population living with the hazard zones identified surrounding the industries can be alerted.

1.5 Health

Due to the country's very high population density, pollution and environment, Bangladesh is highly conducive for emerging diseases. The Directorate General of Health Services (DGHS), under the Ministry of Health and Family Welfare (MoHFW), Government of Bangladesh in partnership with the World Health Organization compiles and manages epidemic surveillance system for the country. However, very limited assessments and mapping work have been carried out at the national and local levels. ADPC has carried out disease and outbreak susceptibility mapping based on the Incidence Index in Nepal. With this experience, keeping in view of health bulletins and other information hosted by the Director General of Health Service (DGHS) in their website (www.dghs.gov.bd), necessary data is collected for the most predominant communicable diseases prevailing in the country for the year 2011, 2012 and 2013 and health hazard assessment is carried out in this study.

1.5.1 Data Used

1.5.1.1 Monthly Disease Profile Data

In their website, DHGS (www.dghs.gov.bd) reports the number people at the district level for 157 diseases (Figure 1.45) in all the 64 districts of Bangladesh. This data is available as a *Monthly Disease Profile Report* on monthly basis with details regarding population based on sex (male/female) as well as seven age categories (0 – 28 days, 29 days to 11 months, 1- 4, 5-14, 15-24, 25-49 and more than 50 years), as shown in Figure 1.44.

Government of the People's Republic of Bangladesh
MIS-Health, Directorate General of Health Sevices
Mohakhali, Dhaka-1212, Bangladesh

Monthly Disease Profile Report

Organisation Unit : Barguna District
Reporting Month and Year : Apr-2012

Sl.	Disease	0-28 days		29 days-11 mo		1-4 years		5-14 years		15-24 year		25-49 year		50+ years		Total		Gra
1	Abortion	0	0	0	0	0	0	0	1	0	15	0	20	0	0	0	36	36
50	Diarrhea	0	0	12	6	25	6	10	8	9	17	29	45	18	25	103	107	210

Figure 0.44: Sample Monthly Disease Profile report

Source: www.dghs.gov.bd

The Monthly Disease Profile Reports are generated for of 157 diseases (Figure 1.45). The eight most communicable diseases, namely Dengue, Diarrhea, Encephalitis, Filariasis, Kala-azar, Leprosy, Malaria, Tuberculosis (Pulmonary), are considered for health hazard assessments, along with water borne diseases such as Arsenicosis. This data has been collected for the years 2011, 2012 and 2013 on monthly basis for all the districts and analyzed in this study, using the methodology explained in Section 1.5.2.

1.5.1.2 Population Data

Population data at the district level was collected from census data of 2011 (BBS, 2012). Details available for the population data are as follows:

- Total Population
- Population Male
- Population Female
- Percentage of Population in age group of 0 - 4
- Percentage of Population in age group of 5 - 9
- Percentage of Population in age group of 10 - 14
- Percentage of Population in age group of 15 - 19
- Percentage of Population in age group of 20 - 24
- Percentage of Population in age group of 25 - 29
- Percentage of Population in age group of 30 - 49
- Percentage of Population in age group of 50 - 59
- Percentage of Population in age group of 06 - 64
- Percentage of Population in age group above 65

List of diseases/conditions in the morbidity profile form and used in morbidity profile estimation. is shown in Table 1.20.

Table 0.20: List of Diseases / Conditions in the morbidity profile form

1.	Abortion
2.	Acid Burn
3.	AIDS/HIV
4.	Allergic reaction
5.	Anal fistula
6.	Anemia
7.	Angina pectoris
8.	Ante partum hemorrhage
9.	Appendicitis
10.	Arsenic sis
11.	Arthritis
12.	Assault
13.	Bacillary dysentery
14.	Bone tumor
15.	Brain tumor
16.	Bronchial asthma
17.	Bronchietasis
18.	Bronchlotis
19.	Burn (others)
20.	Ca- cervix
21.	Ca-bladder
22.	Ca-breast
23.	Ca-colon
24.	Ca-esophagus
25.	Ca-gall bladder
26.	Ca-kidney
27.	Ca-larynx
28.	Ca-liver
29.	Ca-lungs
30.	Ca-oral cavity
31.	Ca-pancreas
32.	Ca-prostate
33.	Ca-rectum and anal canal
34.	Ca-scrotum
35.	Ca-skin
36.	Ca-stomach
37.	Cataract
38.	Ca-thyroid
39.	Cho cystitis
40.	Cholelithiasis
41.	Chronic obstructive pulmonary diseases
42.	Cirrhosis of liver
43.	Congenital heart diseases
44.	Congestive cardiac failure
45.	Corneal ulcer
46.	CVA
47.	Dengue
48.	Depressive disorders
49.	Diabetes mellitus
50.	Diarrhea
51.	Diphtheria
52.	Disc prolapsed
53.	Drowning/ Near-drowning
54.	Drug reaction
55.	Dysentery
56.	Ectopic pregnancy
57.	Electric shock
58.	Emphysema
59.	Encephalitis

60. Enteric fever
61. Epilepsy
62. Fibroid
63. Filariasis
64. Food poisoning
65. Fracture
66. Fungal infections
67. Gangrene
68. Glaucoma
69. Glomerulonephritis
70. Gonorrhea
71. Hemolytic Jaundice
72. Hemorrhoids (Piles)
73. Head injury
74. Heart failure
75. Hepatic failure
76. Hepatitis
77. Hernia
78. Hydrocephalous
79. Hydrocele
80. Hydronephrosis
81. Hypercholesteremia
82. Hypertension
83. Hyperthyroidism
84. Hypertrophied Prostate
85. Hypothyroidism
86. Infective Endocarditis
87. Intestinal Obstruction
88. Kala-azar
89. Leprosy
90. Leukemia
91. Liver Abscess
92. Lymphoma
93. Lymph sarcoma
94. Malaria (Vivax /Falciparum)
95. Mastoiditis
96. Measles
97. Meningitis
98. Mental retardation
99. Mumps
100. Myocardial infarction
101. Nasal Polyp
102. Nasopharyngal Carcinoma
103. Nephrotic Syndrome
104. Night Blindness
105. Obstructive jaundice
106. Obstructed Labor
107. Orchitis
108. Osteomyelitis
109. Osteosarcoma
110. Ovarian tumor
111. Poisoning
112. Poliomyelitis
113. Postpartum hemorrhage
114. Pancreatitis
115. Pelvic Infectious Disease
116. Peptic Ulcer
117. Perforation (GI Tract)
118. Peripheral Vascular Disease
119. Pleural effusion
120. Pneumonia
121. Pneumothorax
122. Prostatic Tumor
123. Prostatitis
124. Protein Energy Malnutrition
125. Pulmonary fibrosis
126. Pyelonephritis
127. Rabies
128. Rectal prolapse
129. Refractive error
130. Renal failure
131. Renal Ston
132. Retinal Problem
133. Rheumatic fever
134. Rhinitis
135. Rickets
136. Road Traffic Accident
137. Rupture Uterus
138. Scabies
139. Schizophrenia
140. Septicemia
141. Spinal Cord Injury
142. Suppurative Otitis Media
143. Syphilis
144. Tetanus
145. Thalassemia
146. Tonsillitis
147. Tuberculosis (Extra-Pulmonary)
148. Tuberculosis (Pulmonary)
149. Urethritis
150. Urinary Stone Disease
151. Urinary Tract Infection
152. Valvular Heart Disease
153. Viral fever
154. Whooping cough
155. Worm Infestation (Intestinal)
156. Snake Bite
157. Other

Source: DGHS, 2012

Details of the population data (age groups/sex) available from the Monthly Disease Profiles of DGHS and census data are different. Therefore, the data was re-arranged into the below mentioned categories.

- Percentage of Population in age group of 0 – 4
- Percentage of Population in age group of 5 - 14
- Percentage of Population in age group of 15 - 24
- Percentage of Population in age group of 25 - 49
- Percentage of Population in age group above 50

This data was used in the health hazard assessment and analysis.

1.5.2 Methodology

The data collected, as explained in Section 1.5.1, was analyzed using the methodology shown in Figure 1.45.

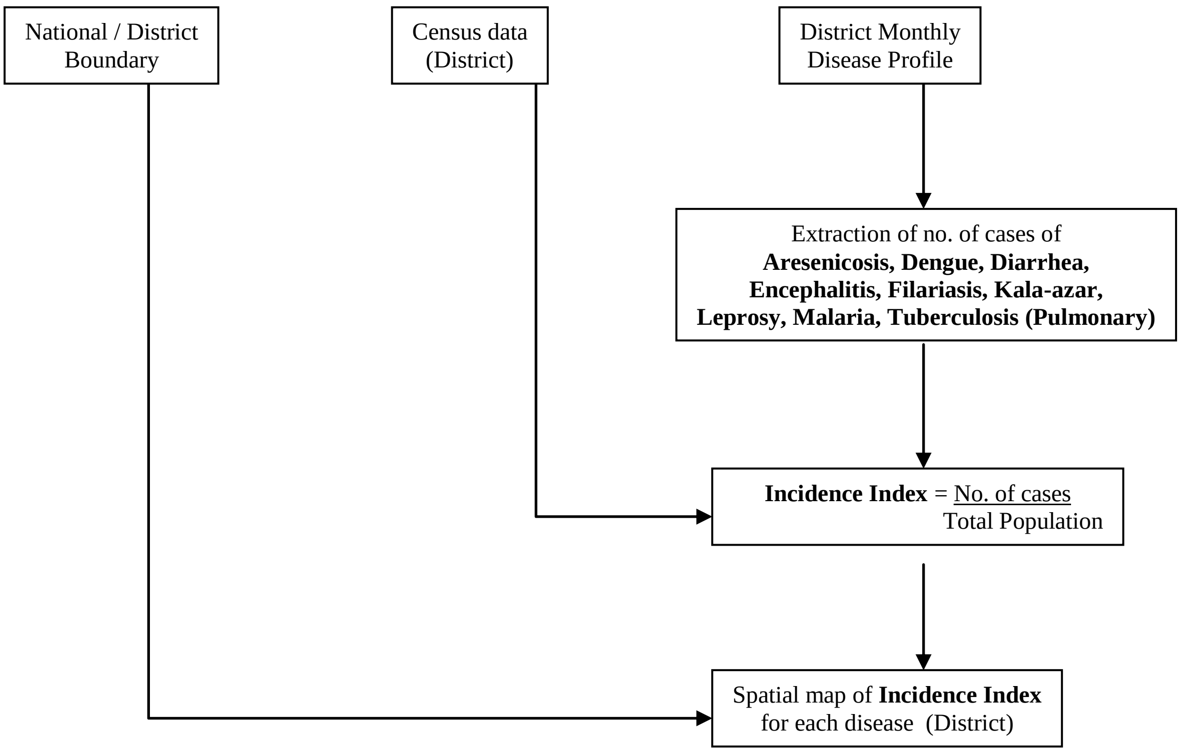


Figure 0.45: Methodology of Health Hazard Assessment

1.5.3 Map Content

The health hazard assessment maps developed represent the number of reported persons for each disease, which are categorized into three classes as given Table 1.21.

Table 0.21: Health hazard categories

Health hazard Category	Number of reported cases	Color symbol used
Low	< 50	
Medium	50 - 100	
High	>100	

1.5.4 Analysis of Hazard Assessment

The number of reported cases of nine diseases analyzed in this study during 2011, 2012 and 2013 in each division is given below.

Arsenicosis

Division Level

The number of reported cases of Arsenicosis during 2011, 2012 and 2013 in each division is given in Figure 1.46.

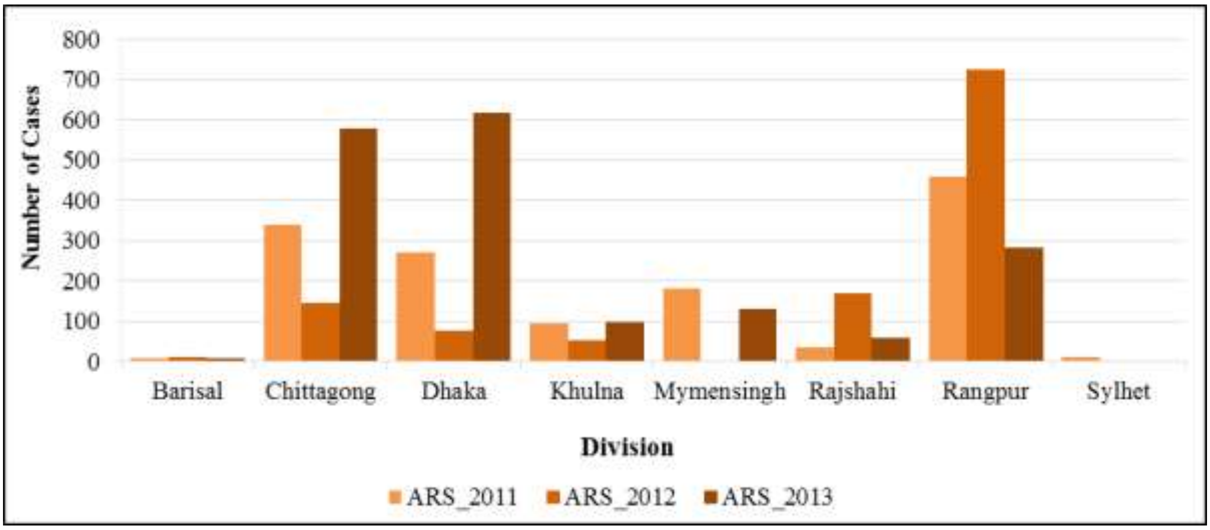


Figure 0.46: Number of cases of Arsenicosis reported in 2011, 2012 and 2013 in each division

Source: DGHS, 2013

In 2013, there were 749 reported cases in Dhaka, and 579 in Chittagong divisions, where as in 2012 they were 724, and in 2011 they were 458 in Rangpur. In addition to the total number of cases annually, the number of reported cases on a monthly basis were also analyzed in each division and the radar diagrams of the worst affected divisions Chittagong in 2013, Dhaka in 2013 and Rangpur in 2012 are shown in Figure 1.47.

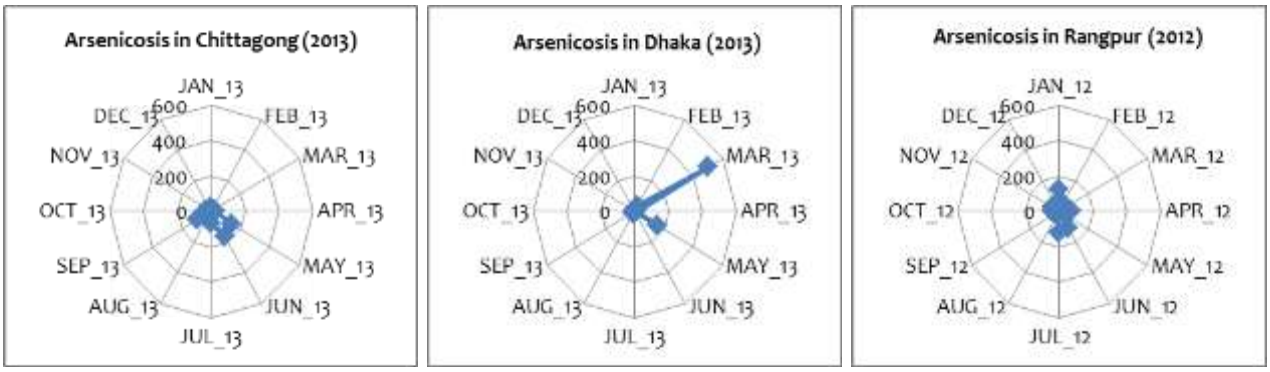


Figure 0.47: Monthly variation of number of reported cases of Arsenicosis in most affected divisions

Source: DGHS, 2013

District Level

The distribution of the number of cases of Arsenicosis in each district during 2011, 2012 and 2013 is shown in Figures 1.48, 1.49 and 1.50.

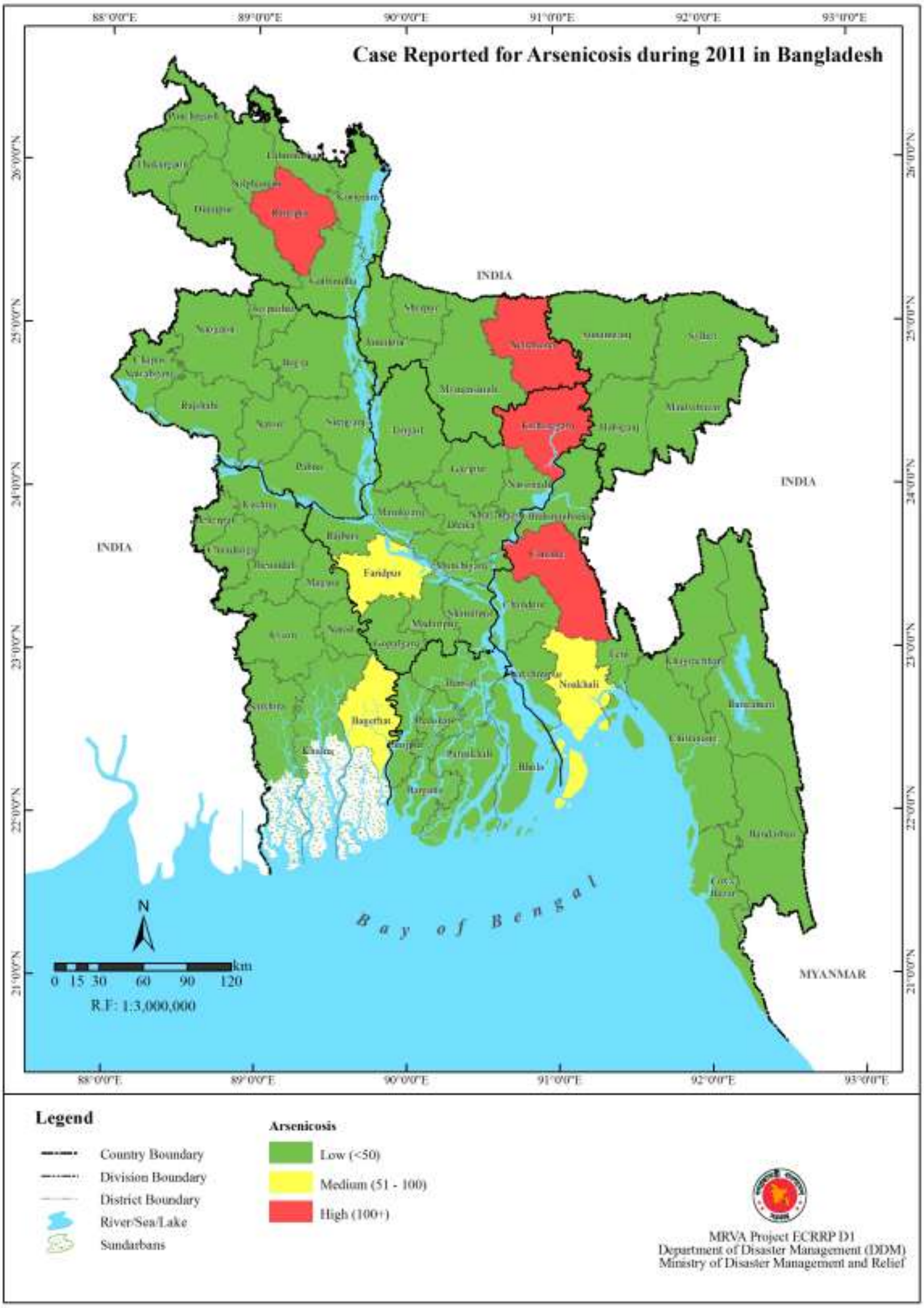


Figure 0.48: Number of cases of Arsenicosis reported in each district in 2011

Source: DGHS, 2013

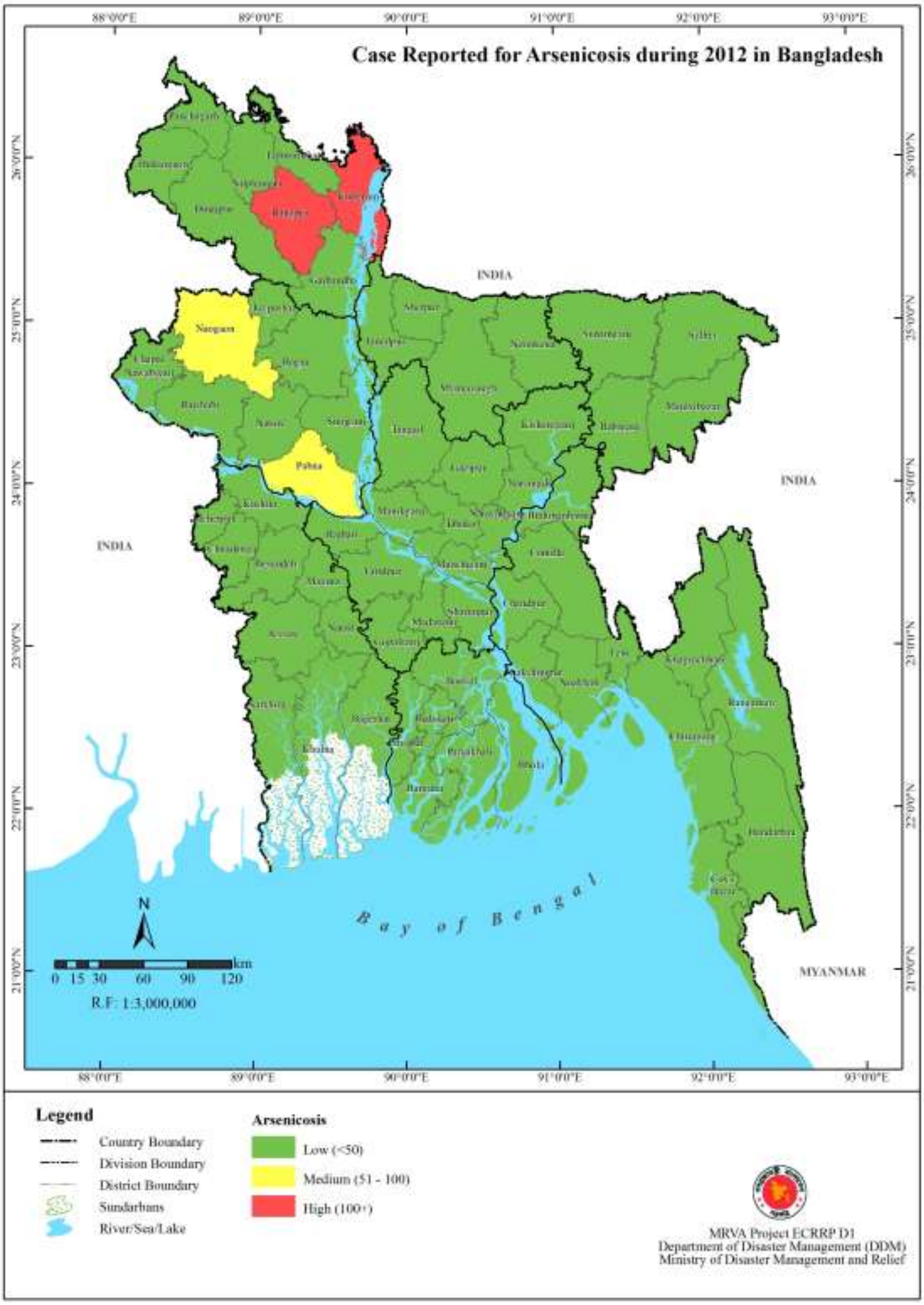


Figure 0.49: Number of cases of Arsenicosis reported in each district in 2012

Source: DGHS, 2013

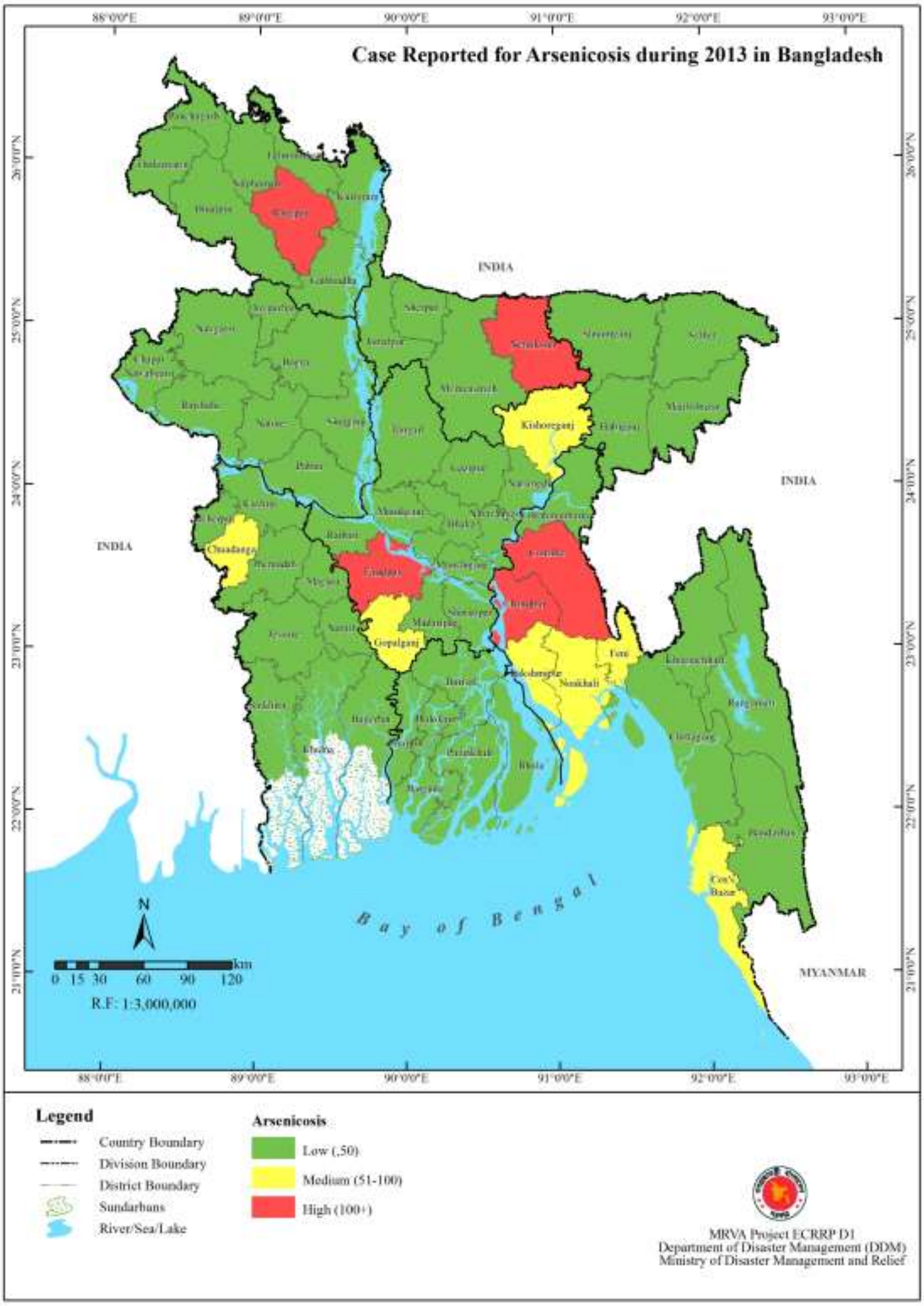


Figure 0.50: Number of cases of Arsenicosis reported in each district in 2013

Source: DGHS, 2013

Dengue

The number of reported cases of Dengue during 2011, 2012 and 2013 in each division is given in Figure 1.51.

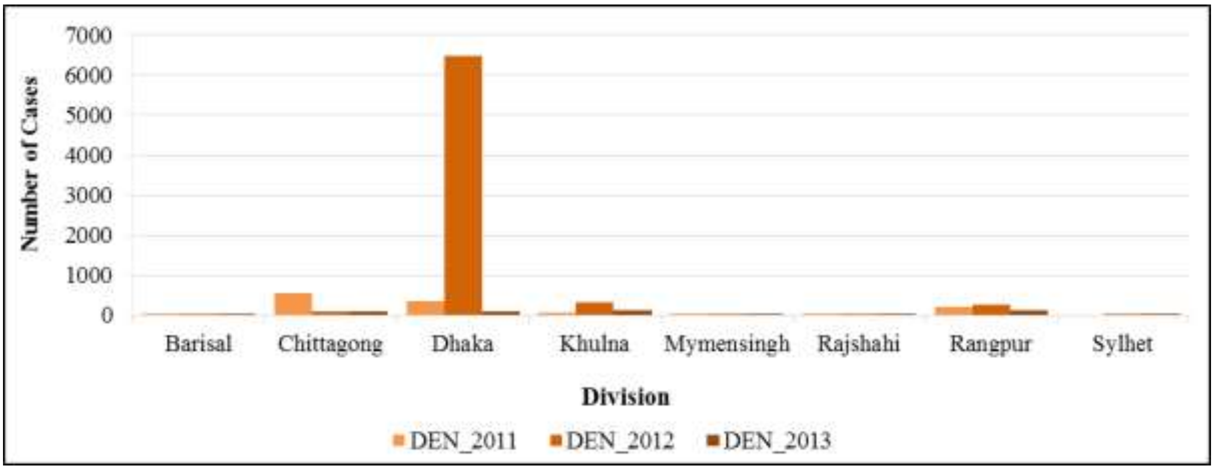


Figure 0.51: Number of cases of Dengue reported in 2011, 2012 and 2013 in each division

Source: DGHS, 2013

The highest number of cases reported was 6,489 in 2012 in Dhaka. In addition to the total number of cases annually, number of reported cases on monthly basis are also analyzed in each division and the radar diagrams of the worst affected division Dhaka in 2012 is shown in Figure 1.52.

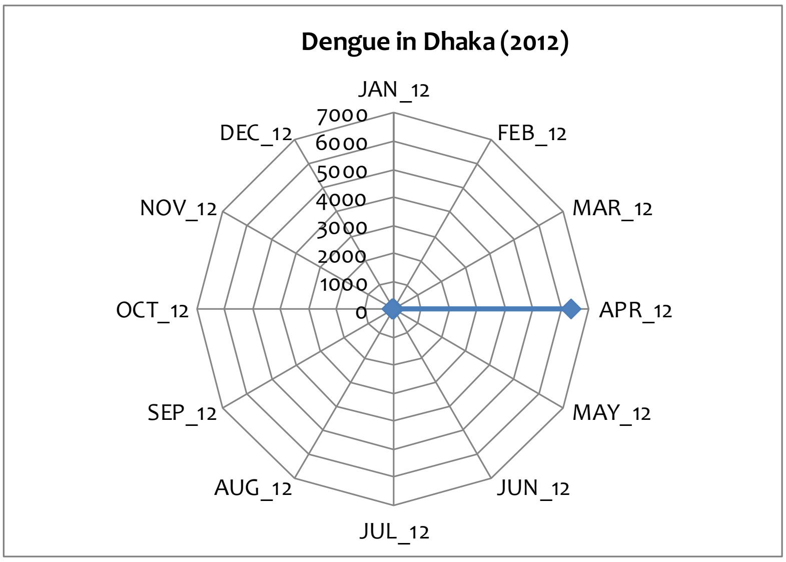


Figure 0.52: Monthly variation of number of reported cases of Dengue in most affected division

Source: DGHS, 2013

District Level

The distribution of the number of cases of Dengue in each district during 2011, 2012 and 2013 is shown in Figures 1.53, 1.54 and 1.55.

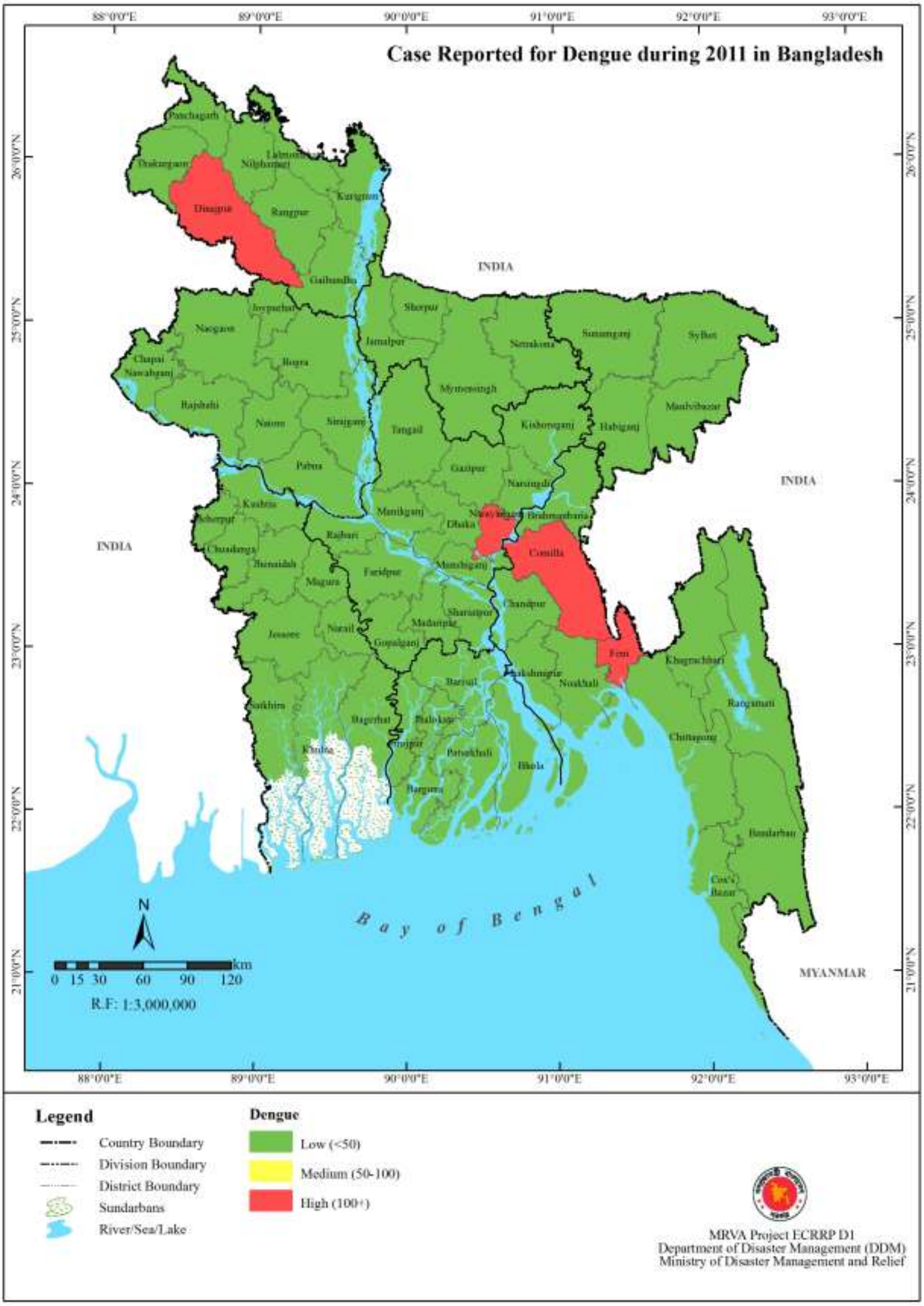


Figure 0.53: Number of cases of Dengue reported in each district in 2011

Source: DGHS, 2013

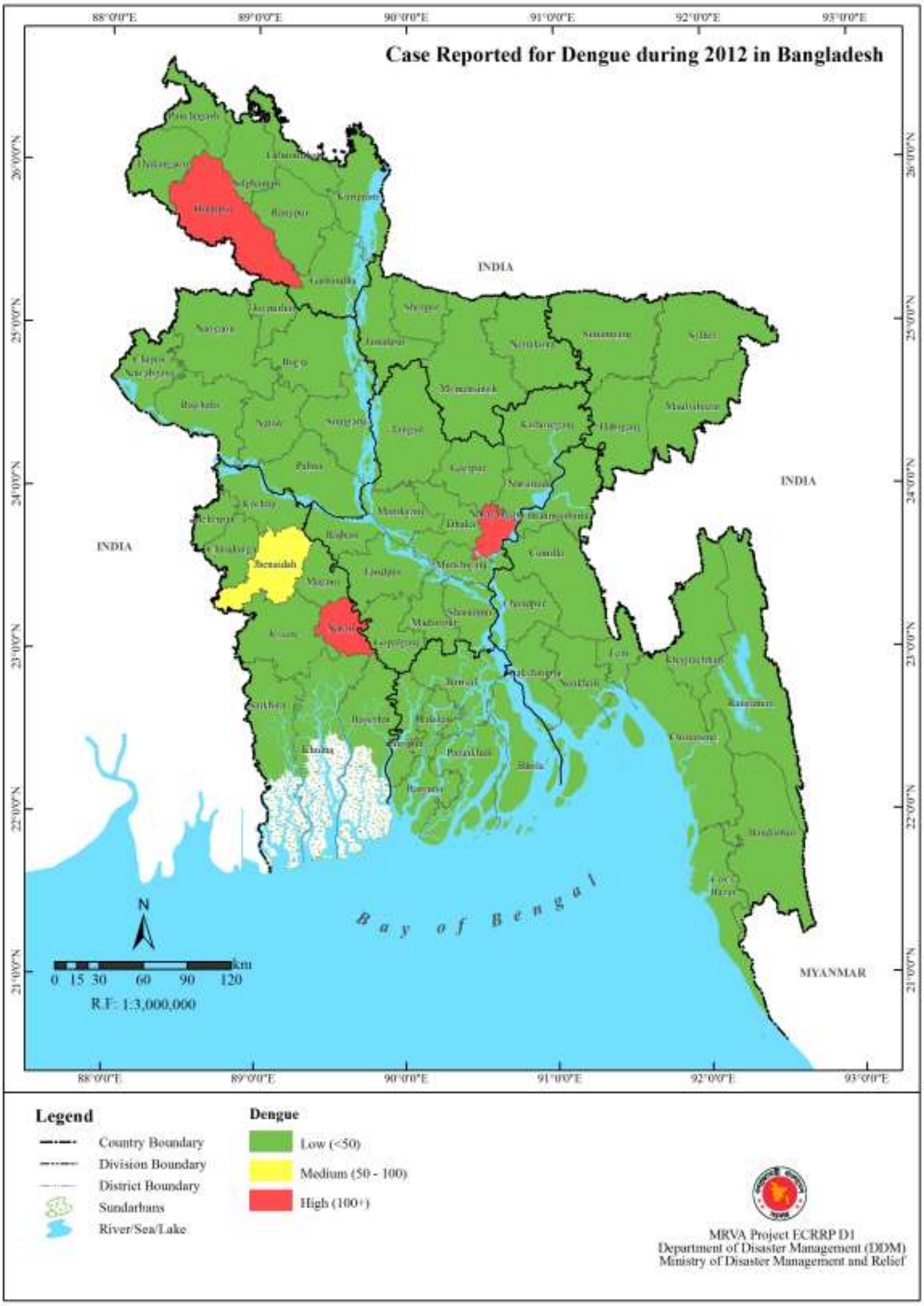


Figure 0.54: Number of cases of Dengue reported in each district in 2012

Source: DGHS, 2013

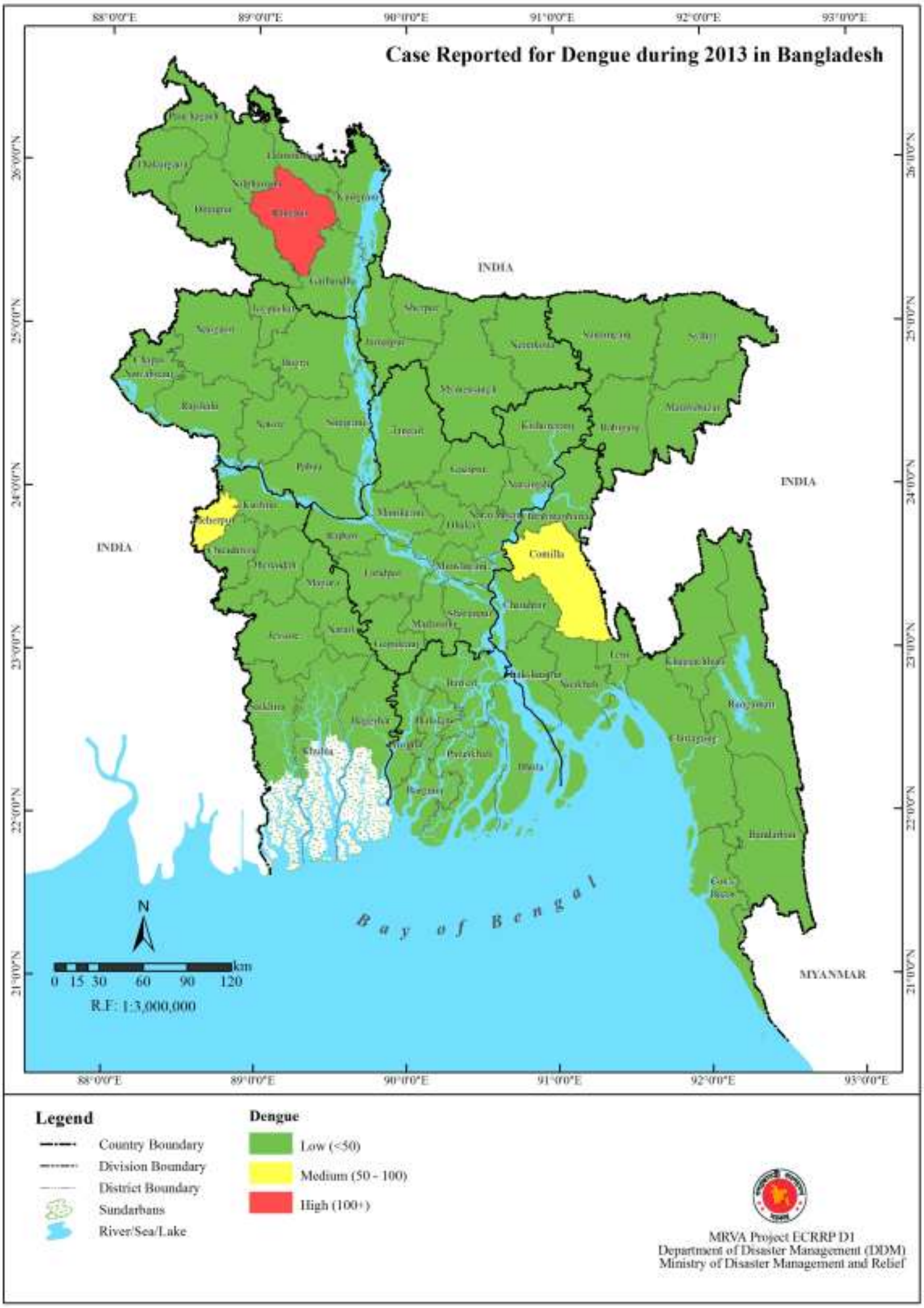


Figure 0.55: Number of cases of Dengue reported in each district in 2013

Source: DGHS, 2013

Diarrhea

The number of reported cases of Diarrhea during 2011, 2012 and 2013 in each division is given in Figure 1.56.

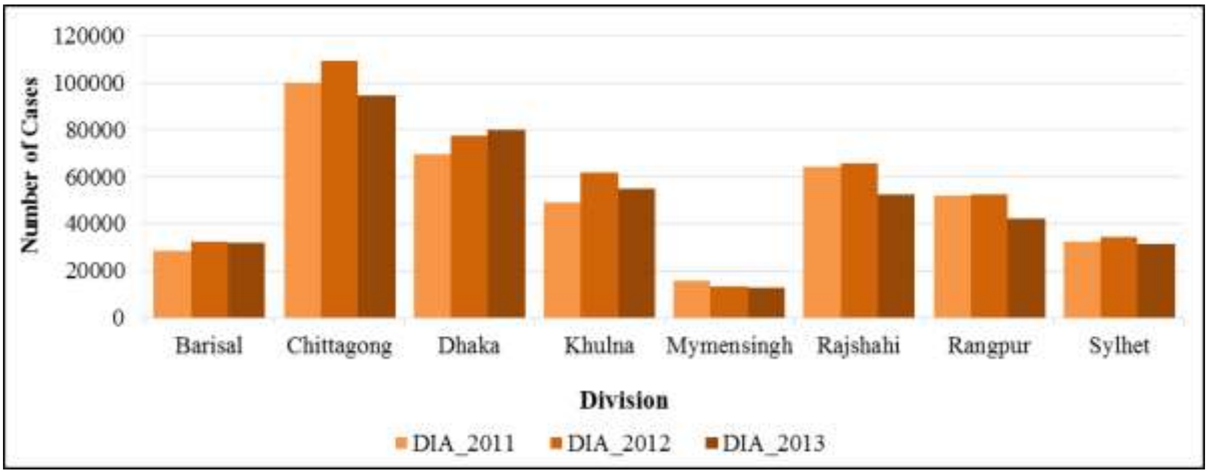
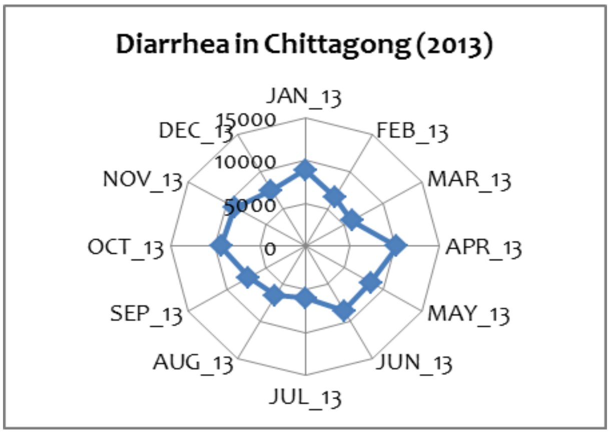


Figure 0.56: Number of cases of Diarrhea reported in 2011, 2012 and 2013 in each division

Source: DGHS, 2013

Overall, Diarrhea has the highest number of cases reported in the whole country with Chittagong and Dhaka divisions reporting highest. In addition to the total number of cases annually, the number of reported cases on monthly basis are also analyzed in each division and the radar diagrams of the worst affected divisions in 2013 are Chittagong and Dhaka, which are shown in Figure 1.57.



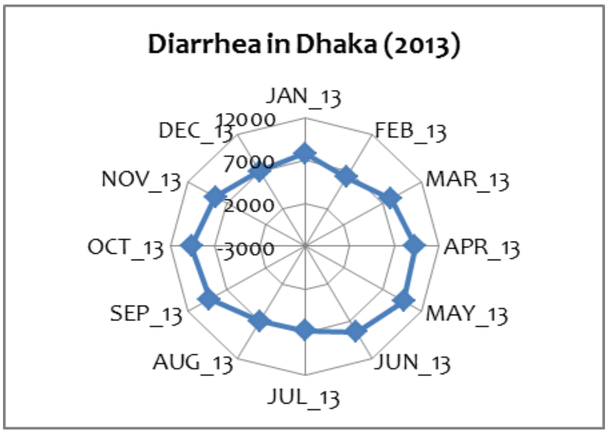


Figure 0.57: Monthly variation of number of reported cases of Diarrhea in most affected divisions

Source: DGHS, 2013

District Level

The distribution of the number of cases of Diarrhea in each district during 2011, 2012 and 2013 is shown in Figures 1.58, 1.59 and 1.60.

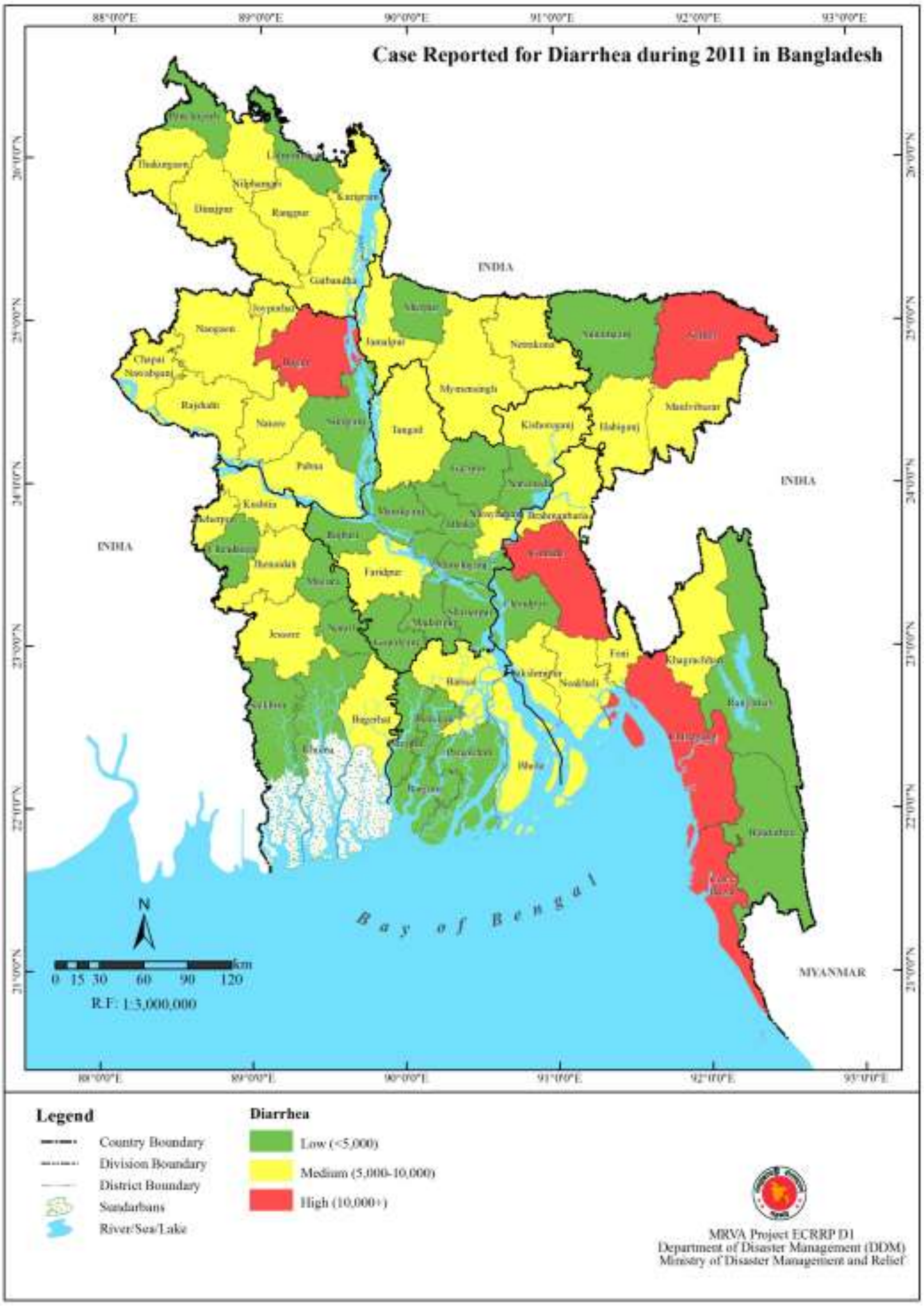


Figure 0.58: Number of cases of Diarrhea reported in each district in 2011

Source: DGHS, 2013

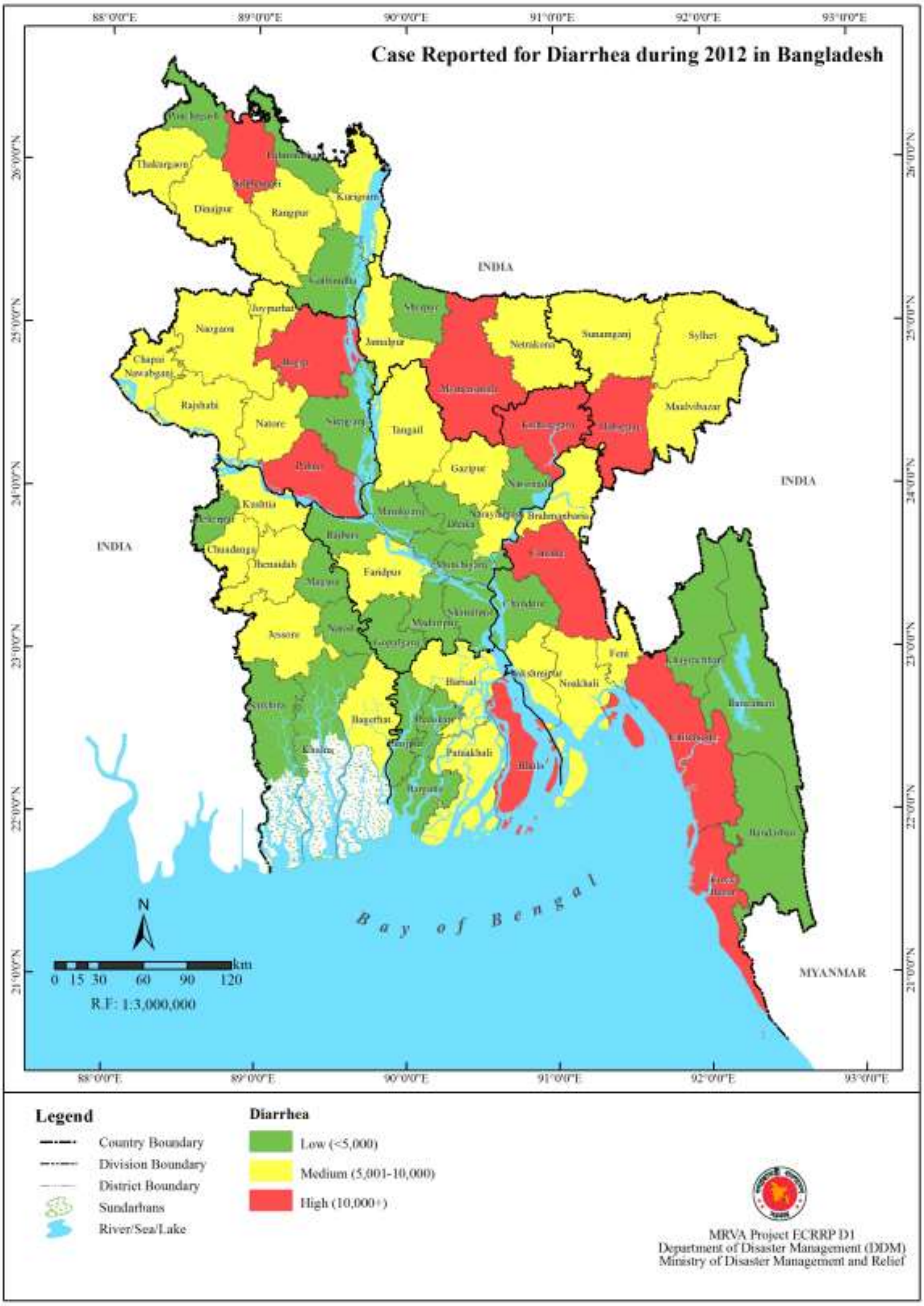


Figure 0.59: Number of cases of Diarrhea reported in each district in 2012

Source: DGHS, 2013

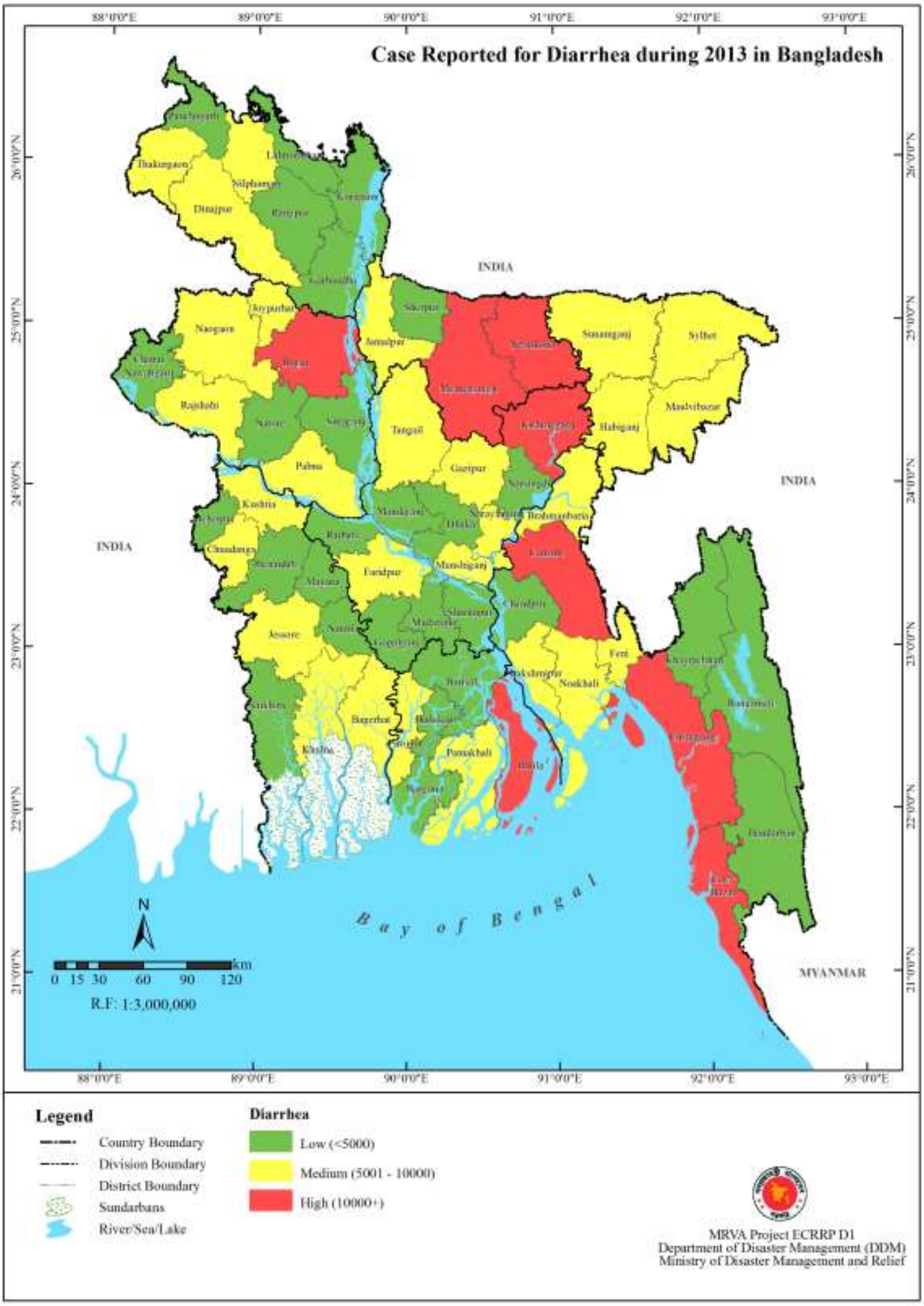


Figure 0.60: Number of cases of Diarrhea reported in each district in 2013

Source: DGHS, 2013

The incidence index described in the methodology section is calculated only for Diarrhea, as number of cases reported for other diseases is very small compared to Diarrhea. The distribution of incidence index at district level for 2011, 2012 and 2013 is shown in Figures 1.61, 1.62 and 1.63.

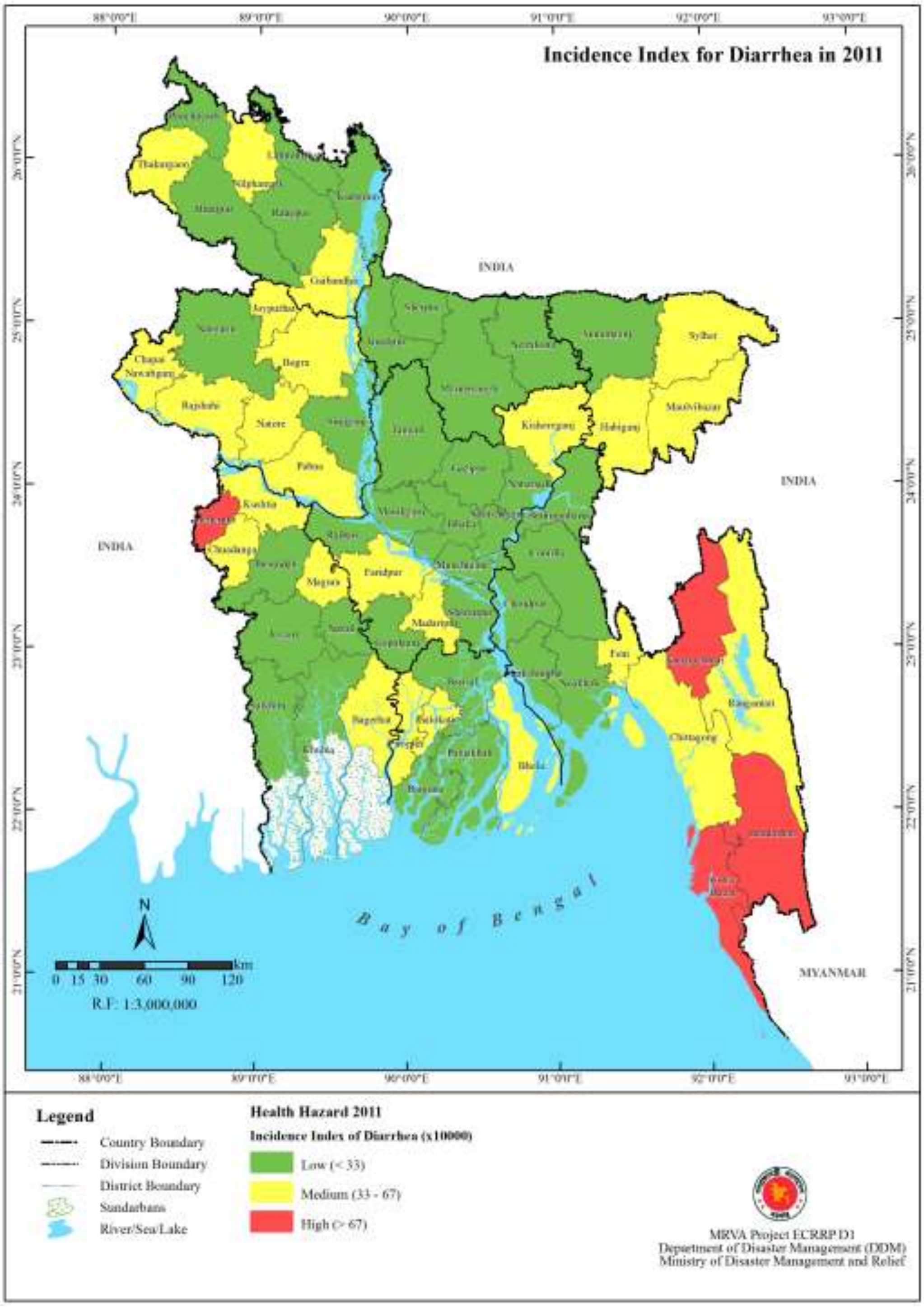


Figure 0.61: Incidence index of Diarrhea cases reported in each district in 2011

Source: DGHS, 2013

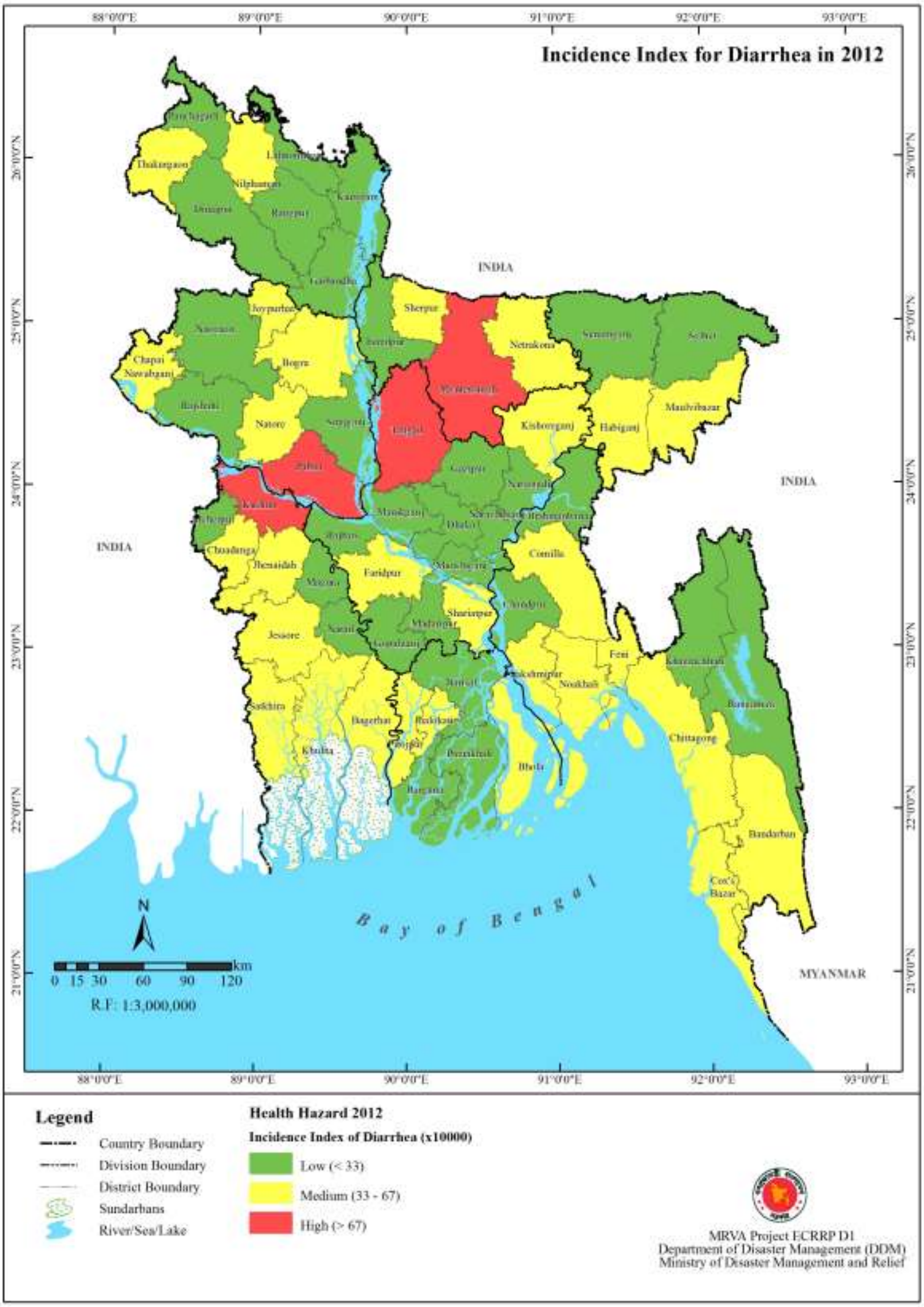


Figure 0.62: Incidence index of Diarrhea cases reported in each district in 2012

Source: DGHS, 2013

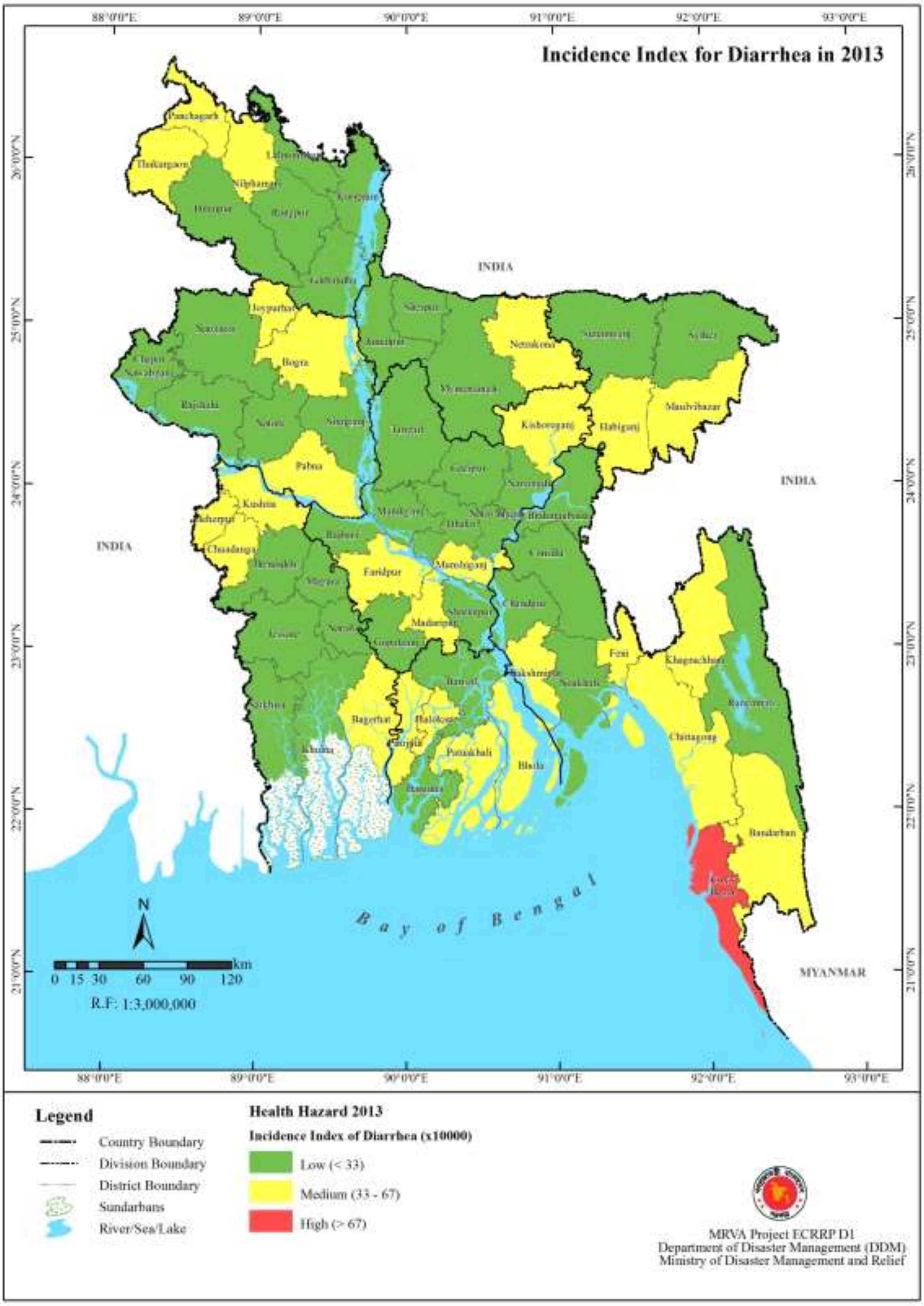


Figure 0.63: Incidence index of Diarrhea cases reported in each district in 2013

Source: DGHS, 2013

Encephalitis

The number of reported cases of Encephalitis during 2011, 2012 and 2013 in each division is given in Figure 1.64.

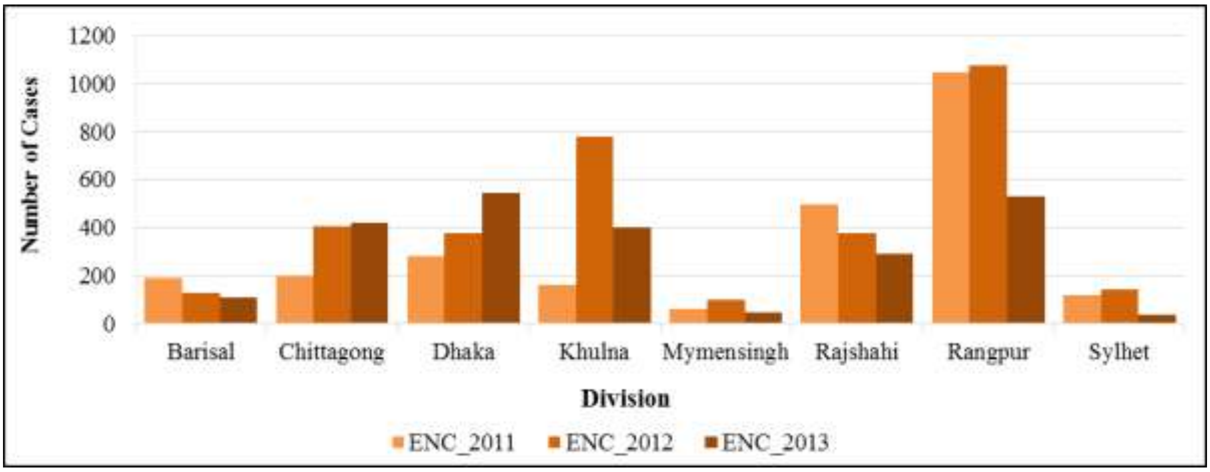


Figure 0.64: Number of cases of Encephalitis reported in 2011, 2012 and 2013 in each division

Source: DGHS, 2013

The highest number of Encephalitis cases were reported in Rangpur division. In addition to the total number of cases annually, the number of reported cases on a monthly basis were also analyzed in each division and the radar diagrams of the worst affected division in 2011, 2012 and 2013 is Rangpur, as shown in Figure 1.65.

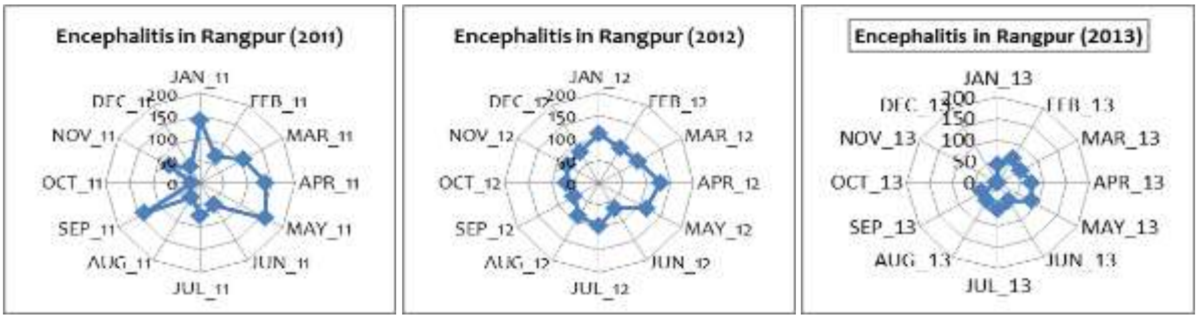


Figure 0.65: Monthly variation of number of reported cases of Encephalitis in most affected divisions

Source: DGHS, 2013

The distribution of the number of cases of Encephalitis in each district during 2011, 2012 and 2013 is shown in Figures 1.66, 1.67 and 1.68.

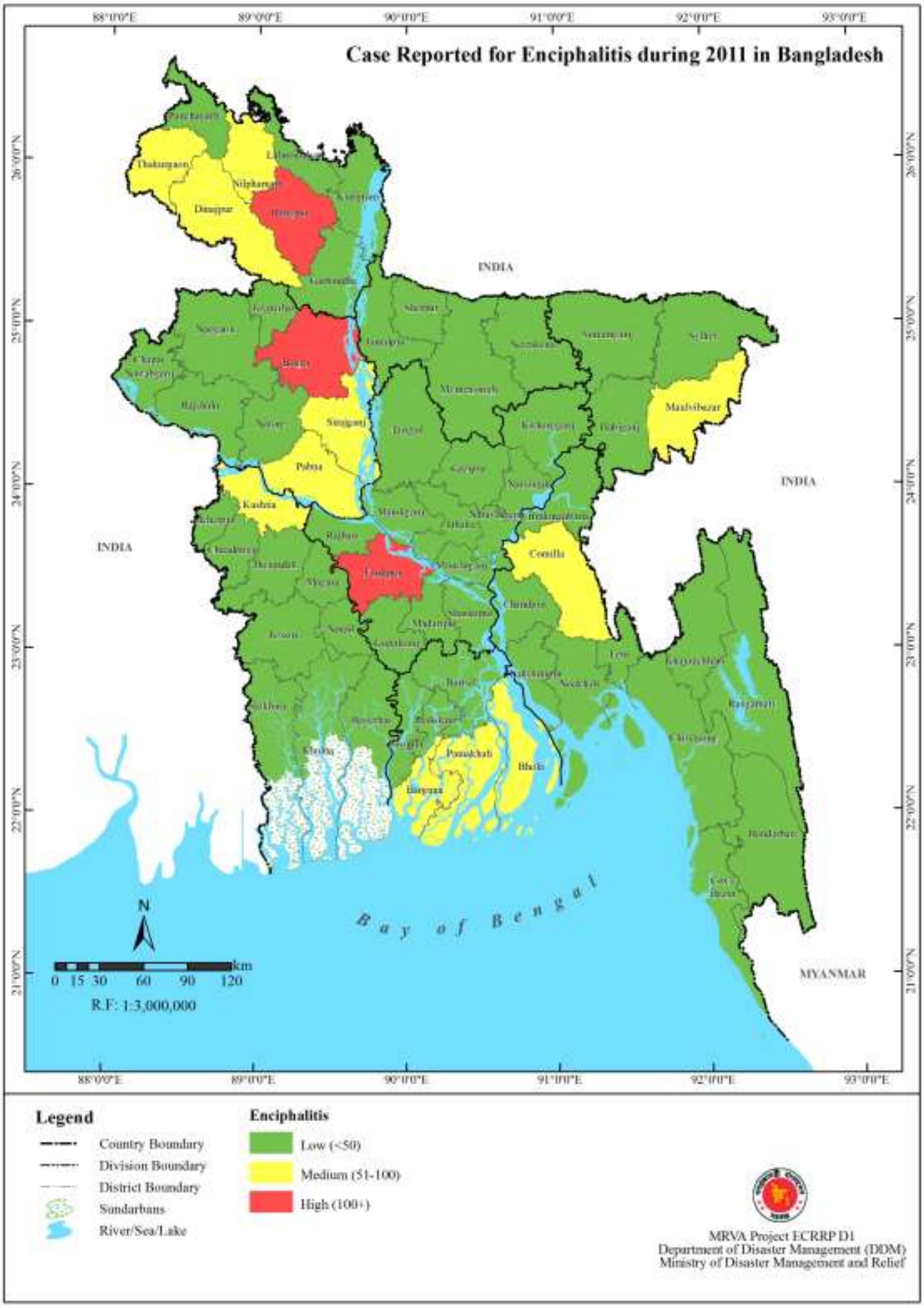


Figure 0.66: Number of cases of Encephalitis reported in each district in 2011

Source: DGHS, 2013

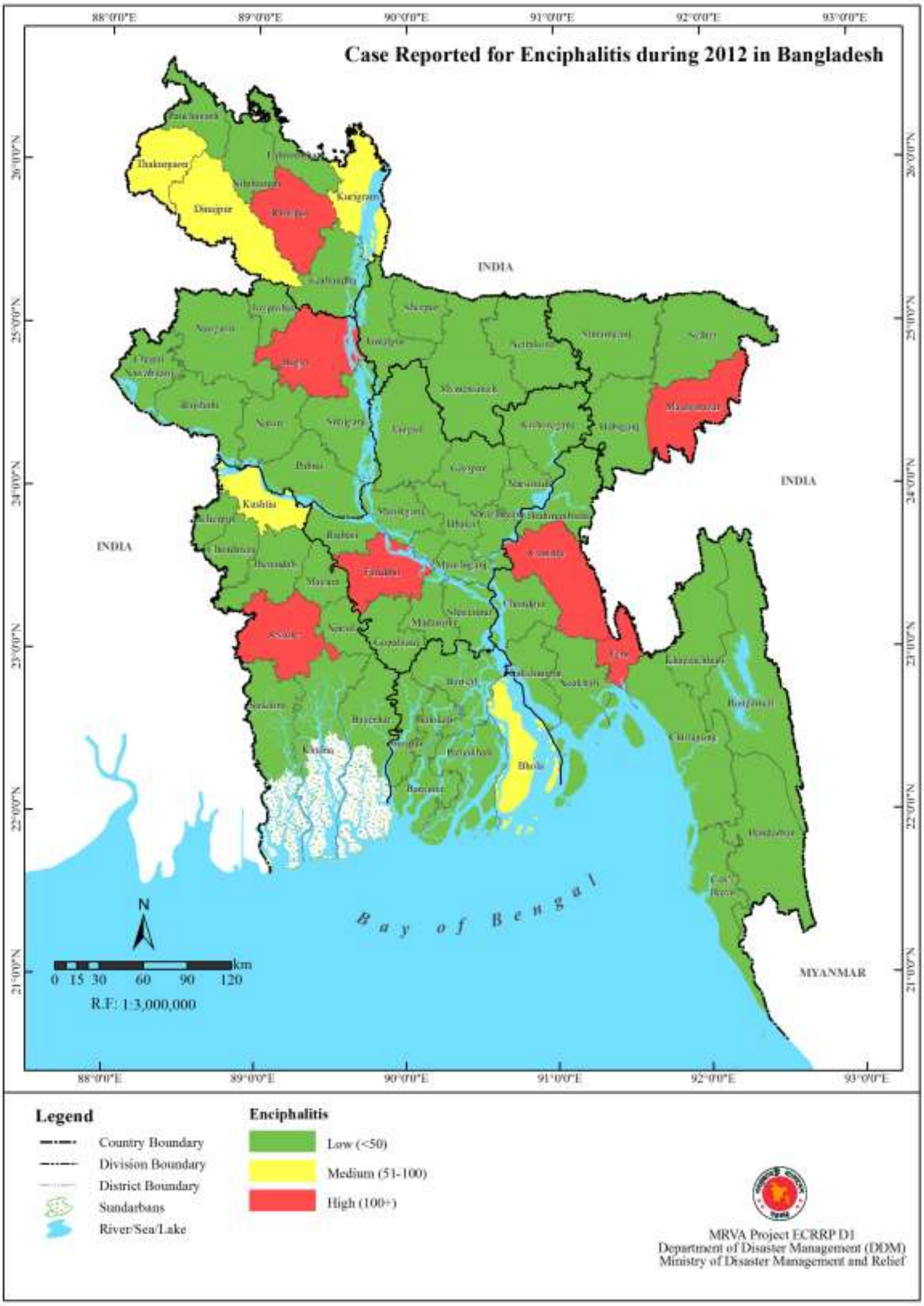


Figure 0.67: Number of cases of Encephalitis reported in each district in 2012

Source: DGHS, 2013

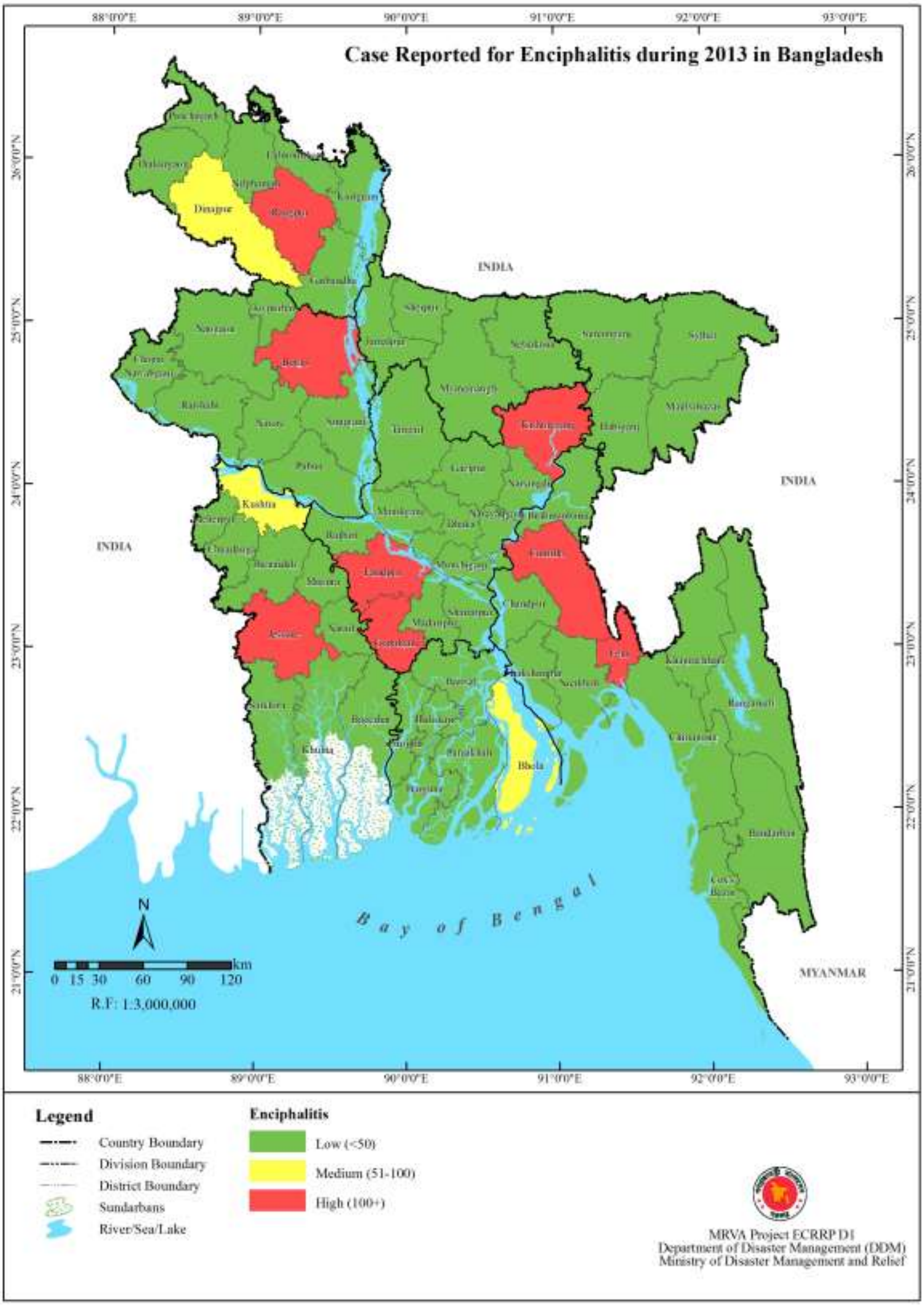


Figure 0.68: Number of cases of Encephalitis reported in each district in 2013

Source: DGHS, 2013

Filariasis

The number of reported cases of Filariasis during 2011, 2012 and 2013 in each division is given in Figure 1.69.

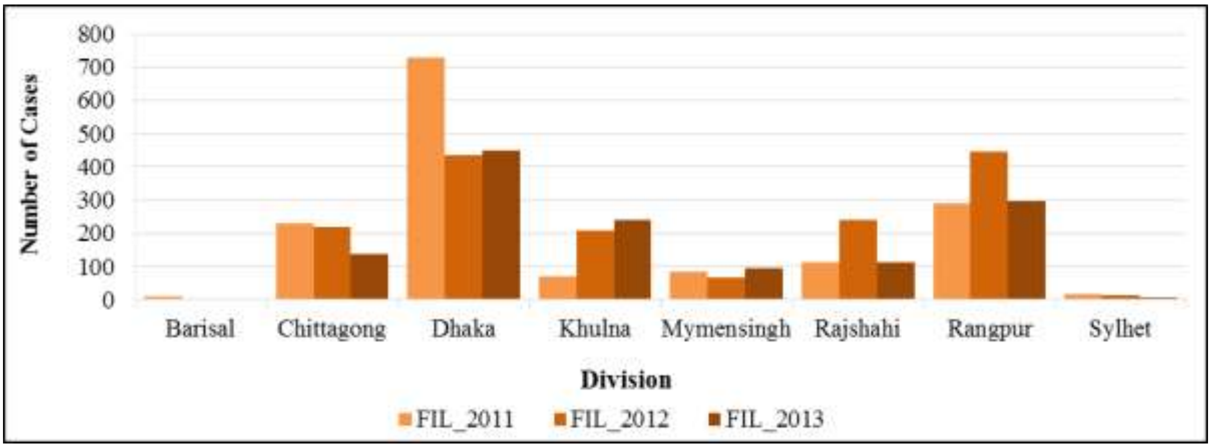


Figure 0.69: Number of cases of Filariasis reported in 2011, 2012 and 2013 in each division

Source: DGHS, 2013

The highest number of Filariasis cases were reported in Dhak division, followed by Rangpur. In addition to the total number of cases annually, the number of reported cases on a monthly basis were also analyzed in each division and the radar diagrams of the worst affected division in 2011, 2012 and 2013 was Dhaka, as shown in Figure 1.70.

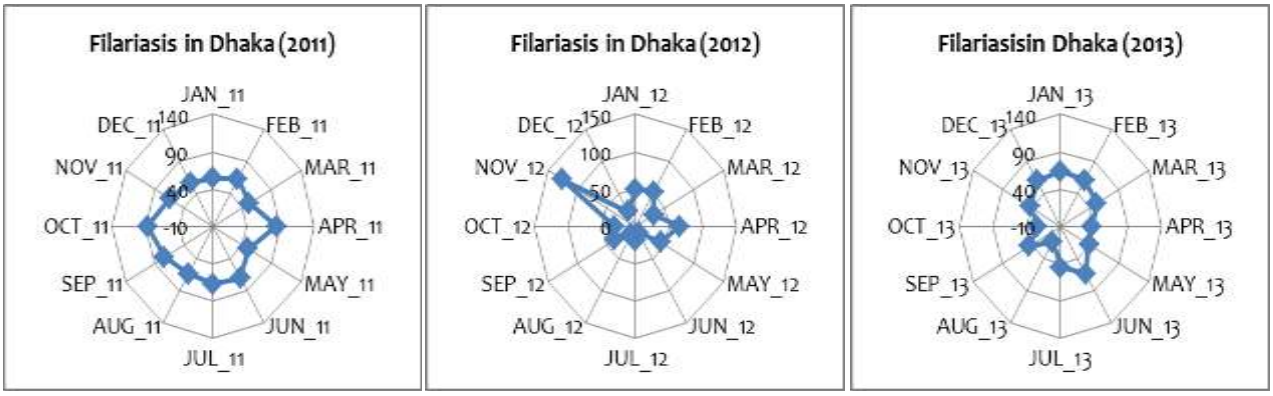


Figure 0.70: Monthly variation of number of reported cases of Filariasis in most affected divisions

Source: DGHS, 2013

The distribution of the number of cases of Filariasis in each district during 2011, 2012 and 2013 is shown in Figures 1.71, 1.72 and 1.73.

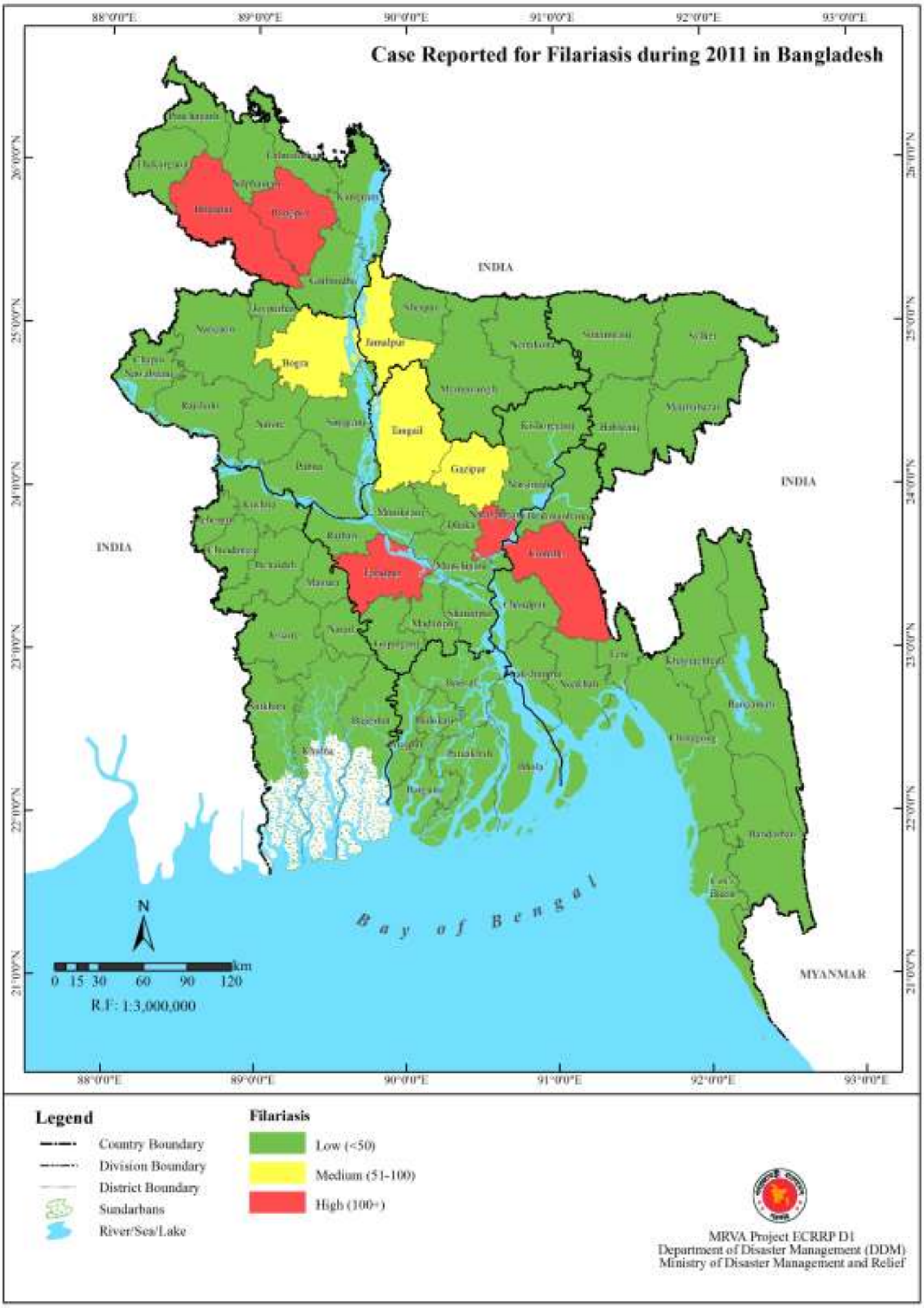


Figure 0.71: Number of cases of Filariasis reported in each district in 2011

Source: DGHS, 2013

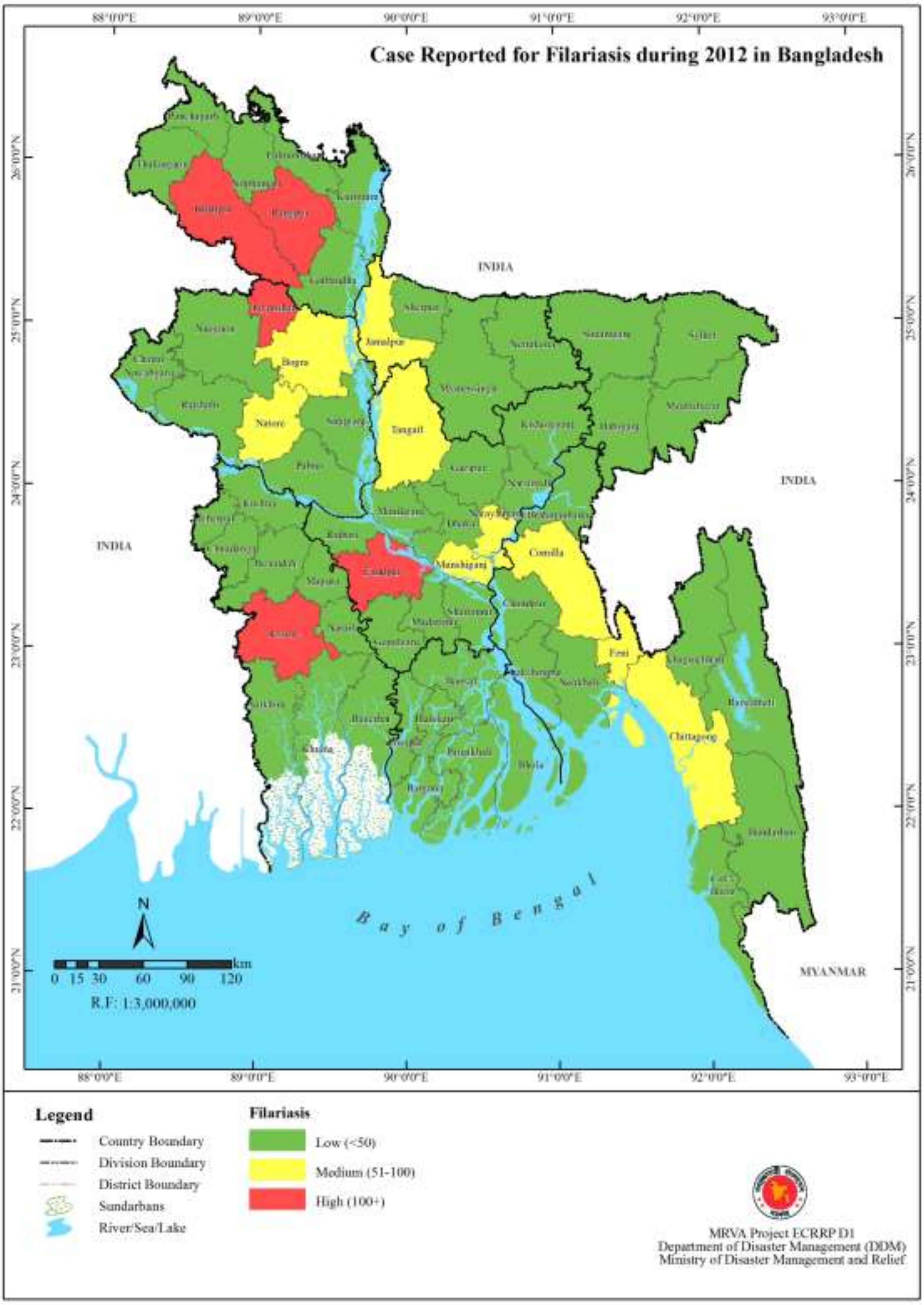


Figure 0.72: Number of cases of Filariasis reported in each district in 2012

Source: DGHS, 2013

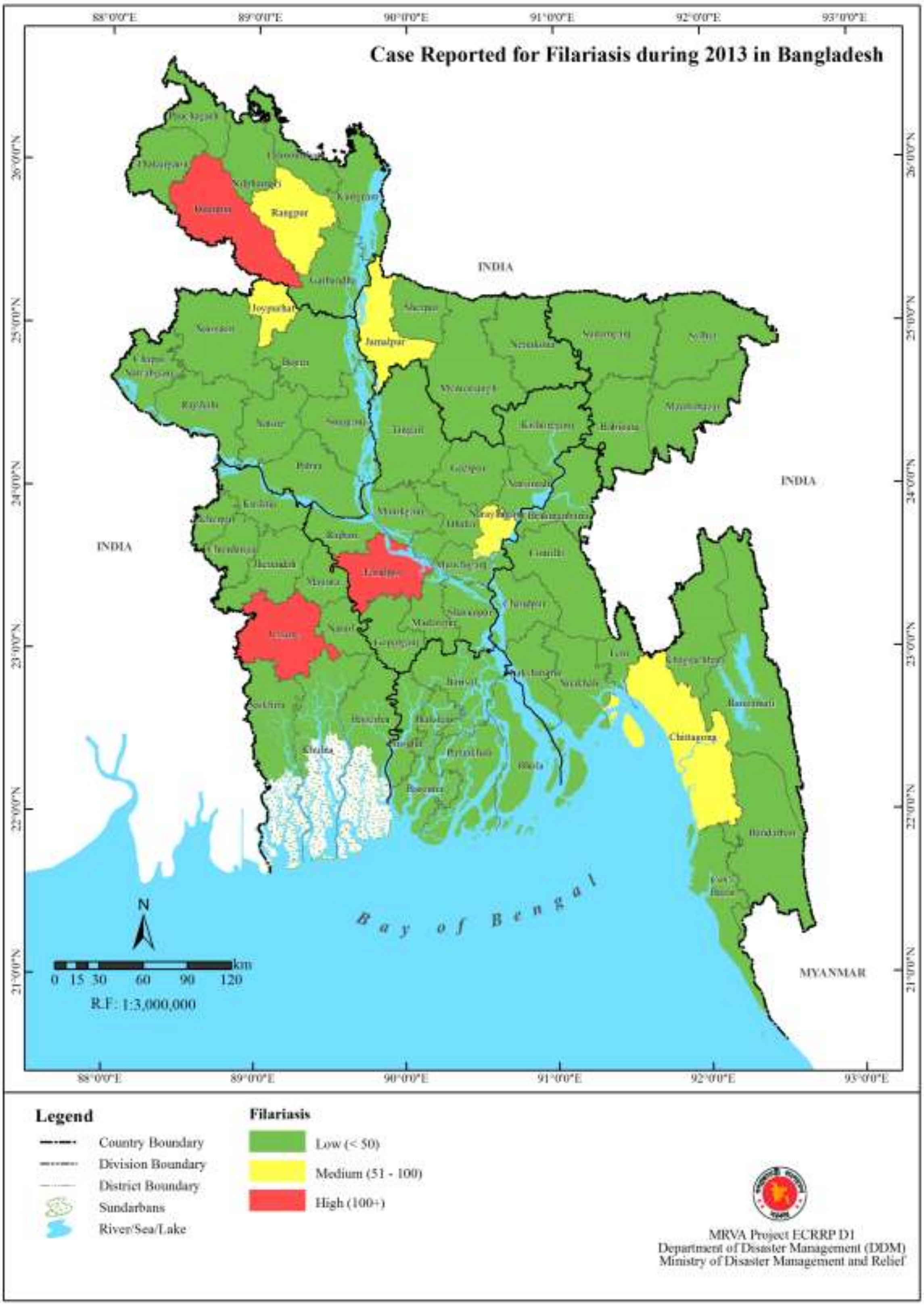


Figure 0.73: Number of cases of Filariasis reported in each district in 2013

Source: DGHS, 2013

Kala-azar

The number of reported cases of Kala-azar during 2011, 2012 and 2013 in each division is given in Figure 1.74.

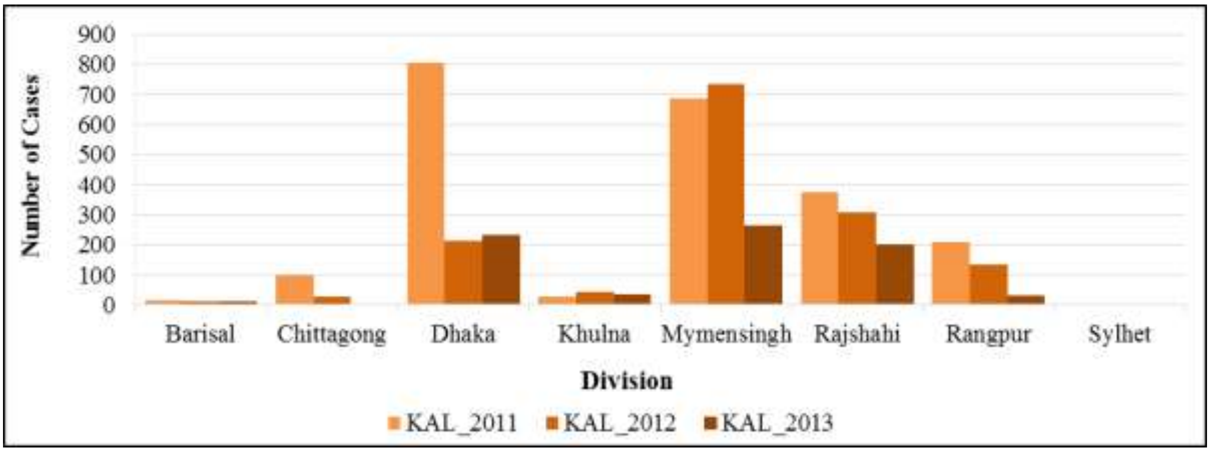


Figure 0.74: Number of cases of Kala-azar reported in 2011, 2012 and 2013 in each division

Source: DGHS, 2013

The highest number of Kala-azar cases were reported in Dhaka division only, followed by Rajshahi. In addition to the total number of cases annually, number of reported cases on a monthly basis were also analyzed in each division and the radar diagrams of the worst affected division in 2011, 2012 and 2013 is Dhaka, as shown in Figure 1.75.

Figure 0.75: Monthly variation of number of reported cases of Filariasis in most affected divisions

Source: DGHS, 2013

The distribution of the number of cases of Kala-azar in each district during 2011, 2012 and 2013 is shown in Figures 1.76, 1.77 and 1.78.

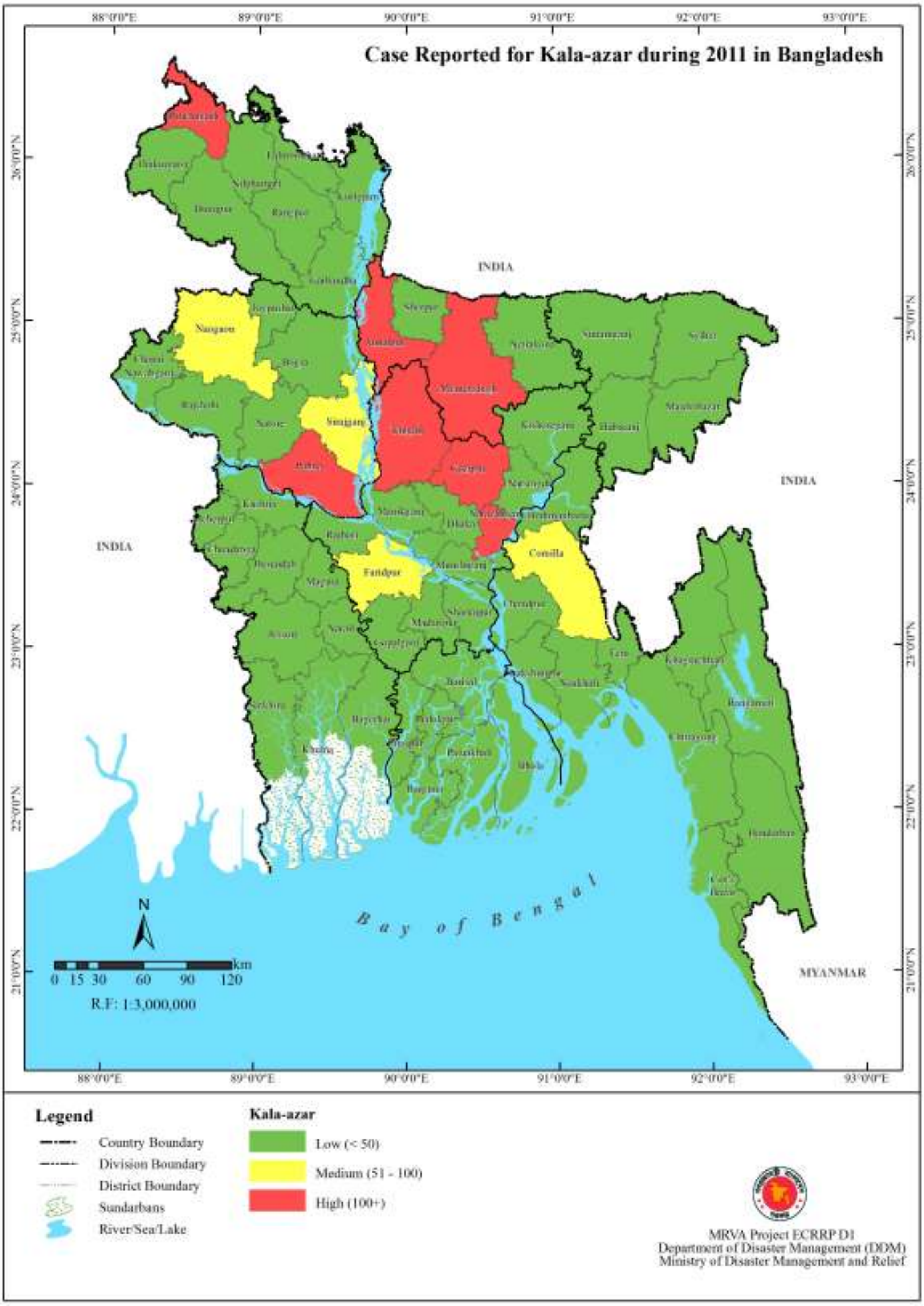


Figure 0.76: Number of cases of Kala-azar reported in each district in 2011

Source: DGHS, 2013

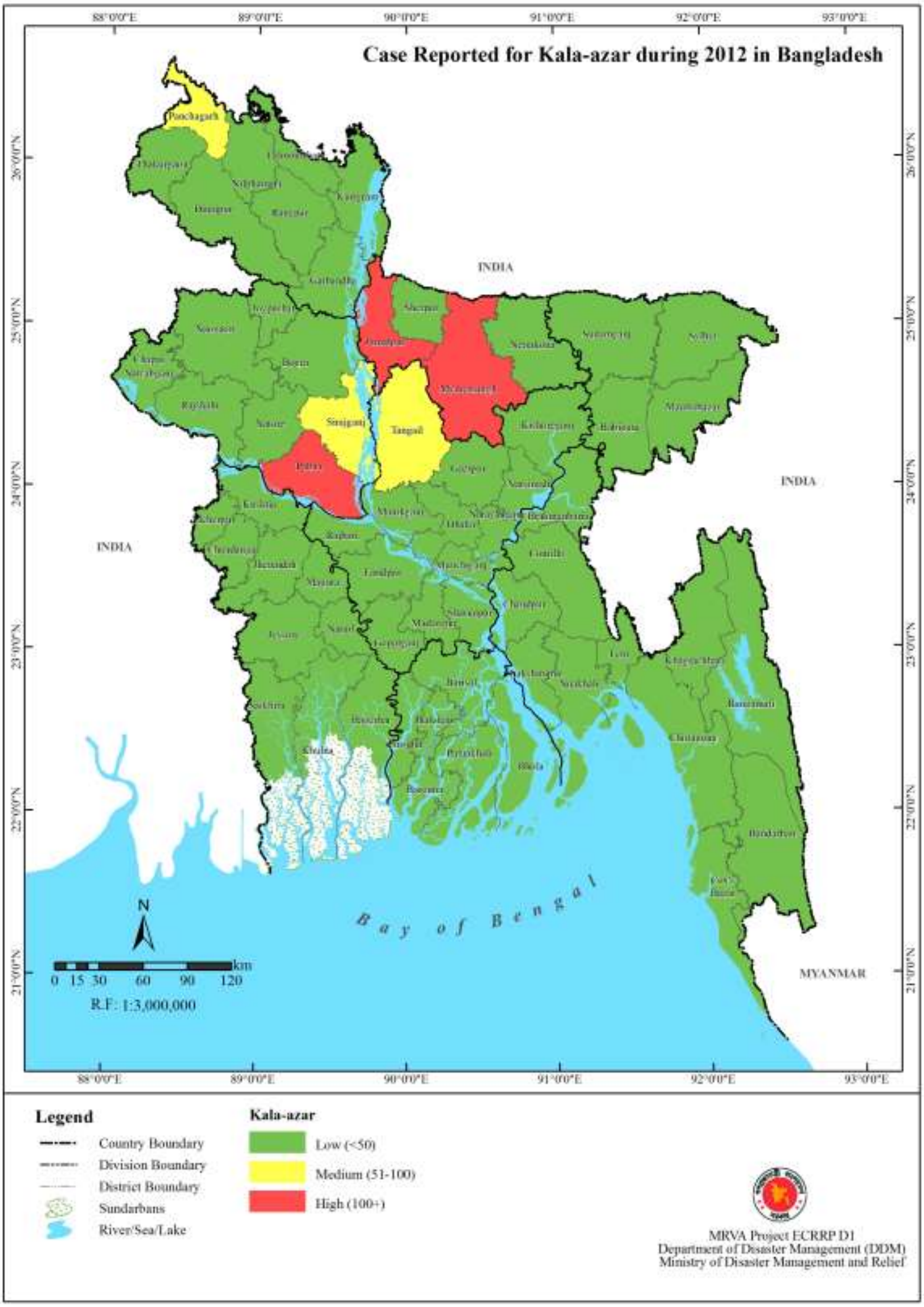


Figure 0.77: Number of cases of Kala-azar reported in each district in 2012

Source: DGHS, 2013

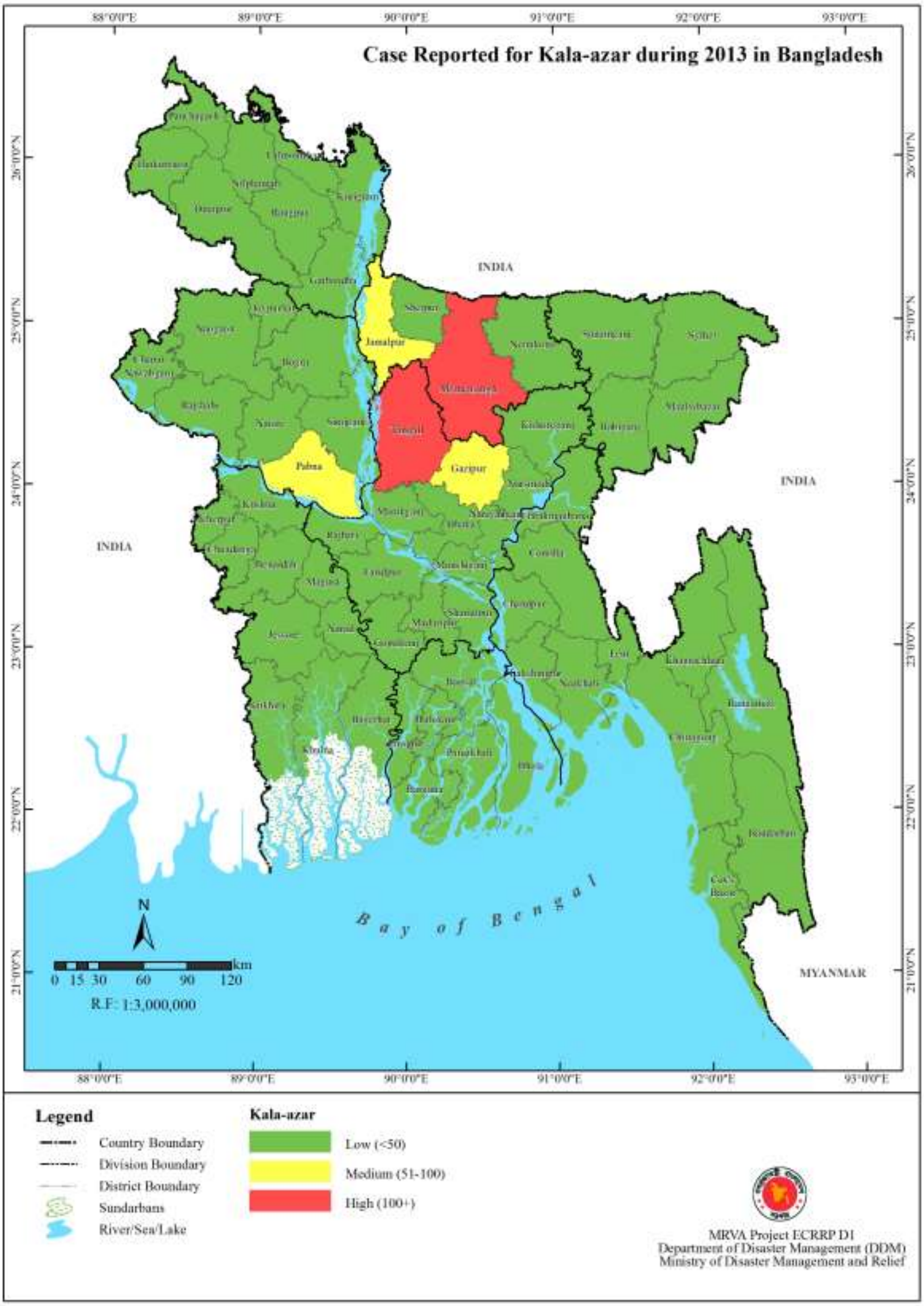


Figure 0.78: Number of cases of Kala-azar reported in each district in 2013

Source: DGHS, 2013

Leprosy

The number of reported cases of Leprosy during 2011, 2012 and 2013 in each division is given in Figure 1.79.

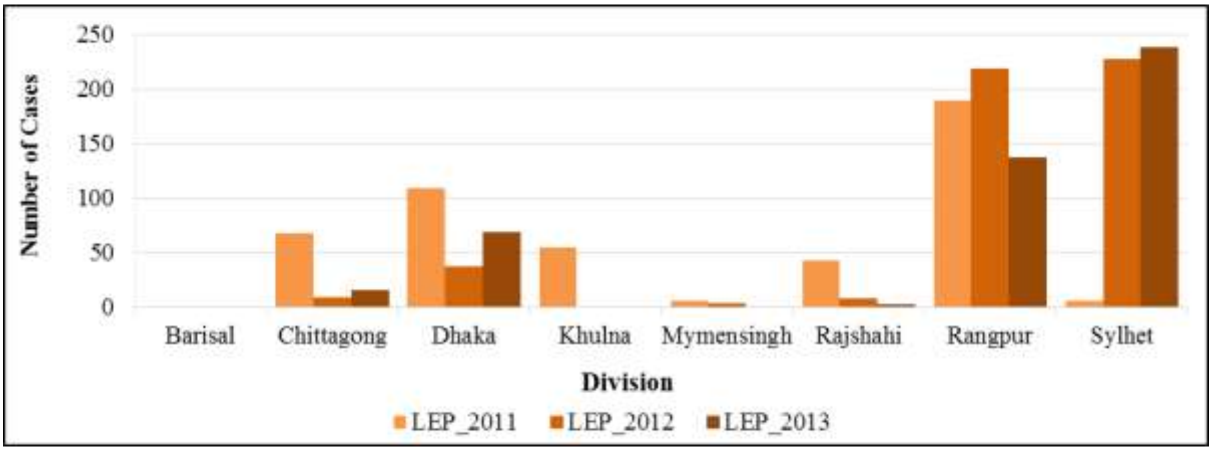


Figure 0.79: Number of cases of Leprosy reported in 2011, 2012 and 2013 in each division
Source: DGHS, 2013

The highest number of Leprosy cases were reported in Sylhet division, followed by Rangpur. In addition to the total number of cases annually, number of reported cases on a monthly basis were also analyzed in each division and the radar diagrams of the worst affected division in 2011 was Rangpur, and in 2012 and 2013 was Sylhet, which are shown in Figure 1.80.

Figure 0.80: Monthly variation of number of reported cases of Leprosy in most affected divisions

Source: DGHS, 2013

The distribution of the number of cases of Leprosy in each district during 2011, 2012 and 2013 is shown in Figures 1.81, 1.82 and 1.83.

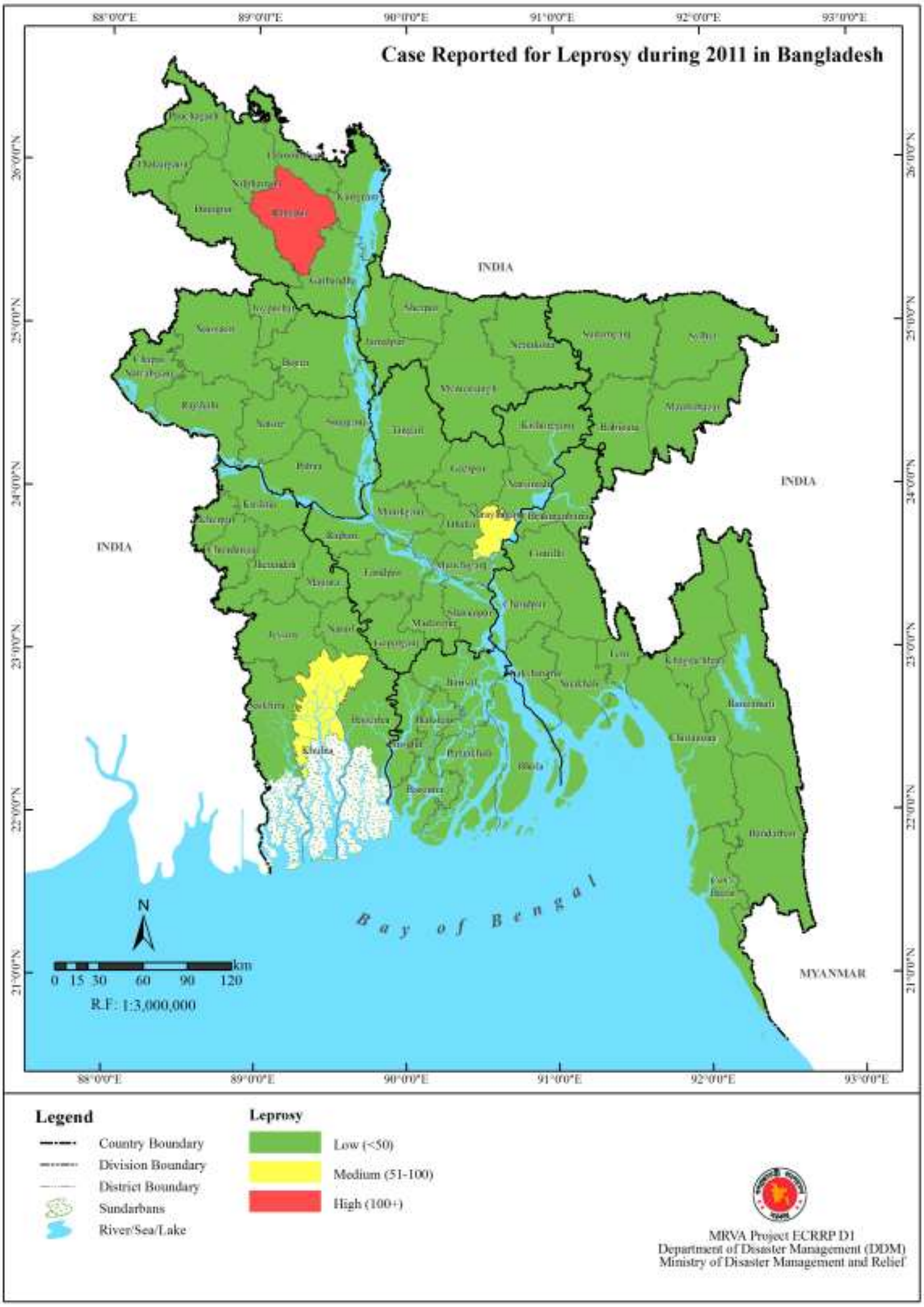


Figure 0.81: Number of cases of Leprosy reported in each district in 2011

Source: DGHS, 2013

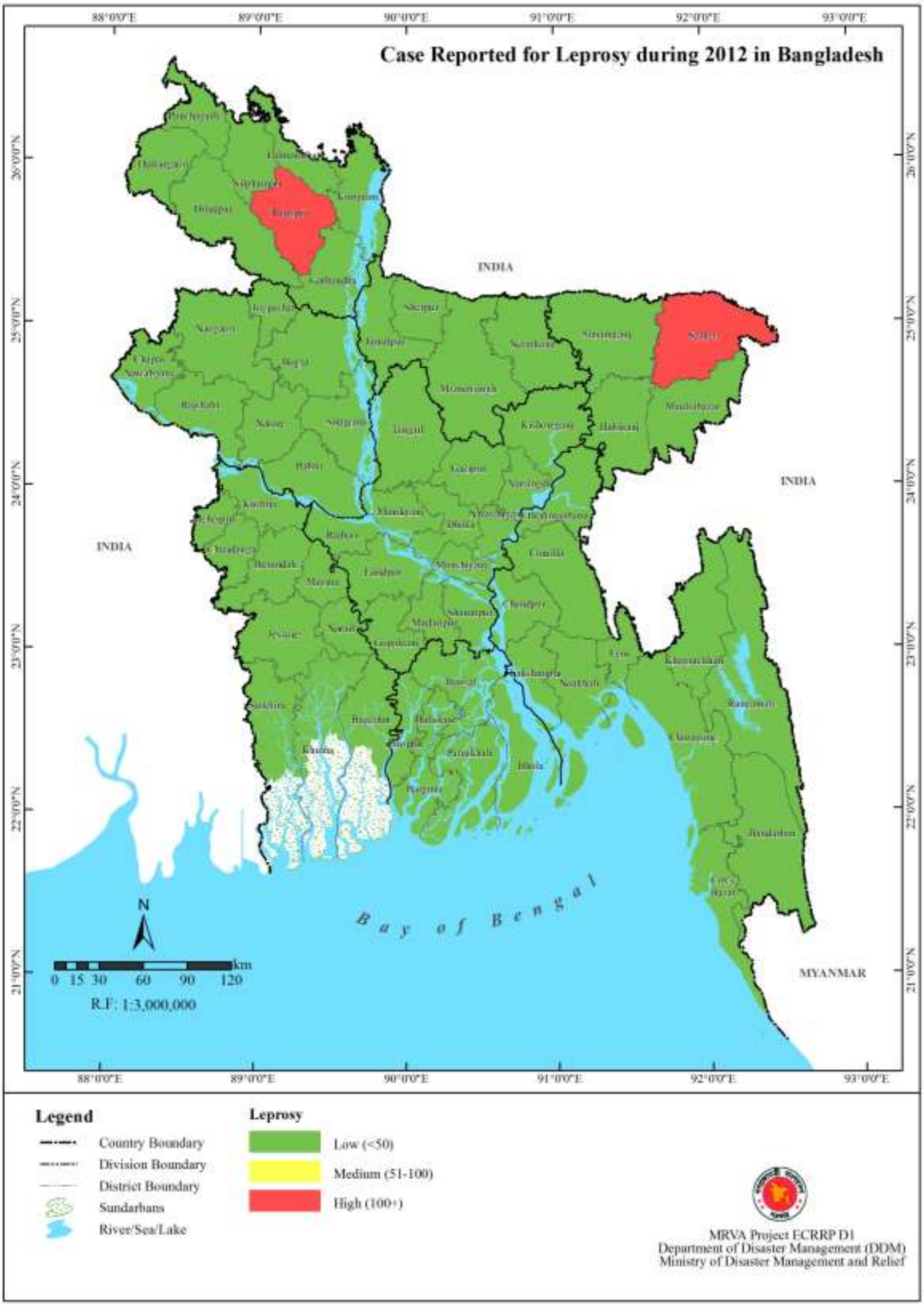


Figure 0.82: Number of cases of Leprosy reported in each district in 2012

Source: DGHS, 2013

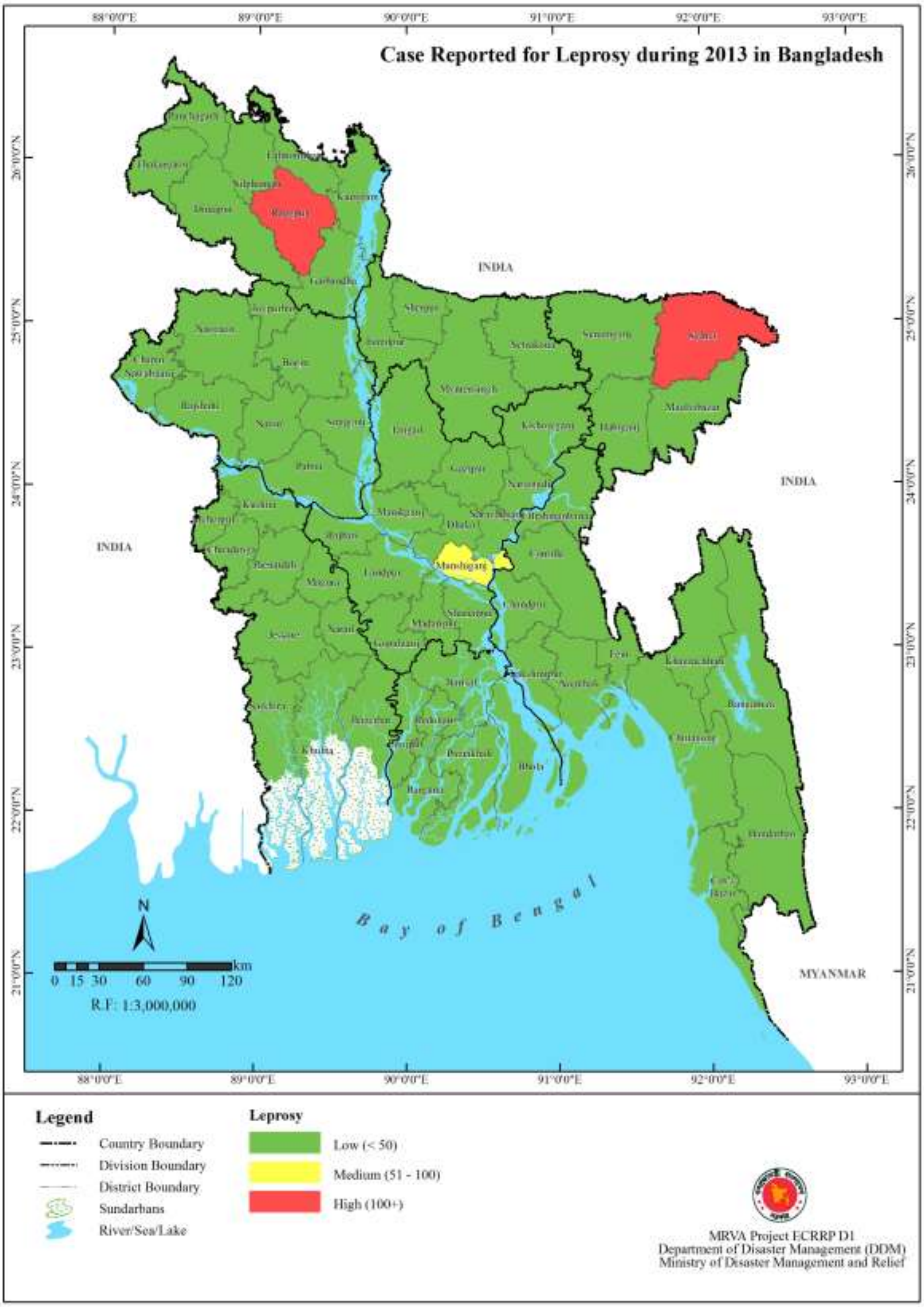


Figure 0.83: Number of cases of Leprosy reported in each district in 2013

Source: DGHS, 2013

Malaria

The number of reported cases of Malaria during 2011, 2012 and 2013 in each division is given in Figure 1.84.

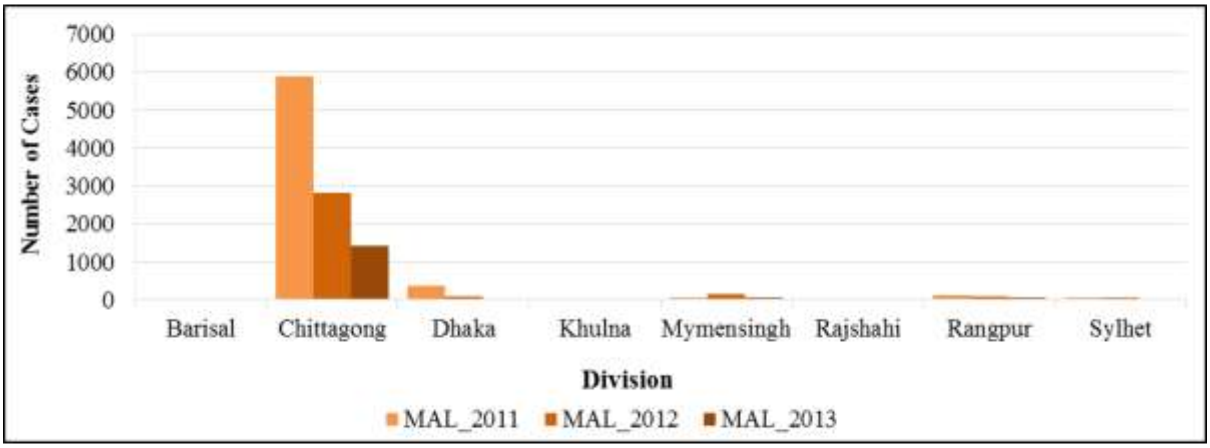


Figure 0.84: Number of cases of Malaria reported in 2011, 2012 and 2013 in each division
Source: DGHS, 2013

The highest number of Malaria cases were reported in Chittagong division only. In addition to the total number of cases annually, the number of reported cases on a monthly basis were also analyzed in each division and the radar diagrams of the worst affected division in 2011, 2012 and 2013 was Chittagong, as shown in Figure 1.85.

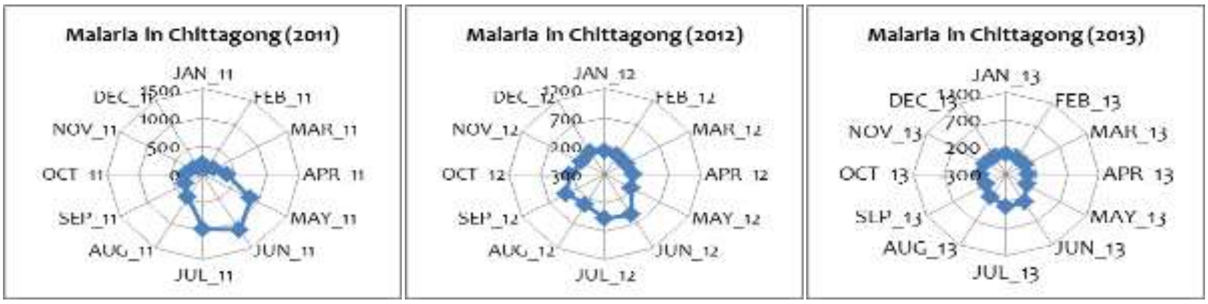


Figure 0.85: Monthly variation of number of reported cases of Malaria in most affected divisions

Source: DGHS, 2013

The distribution of the number of cases of Malaria in each district during 2011, 2012 and 2013 is shown in Figures 1.86, 1.87 and 1.88.

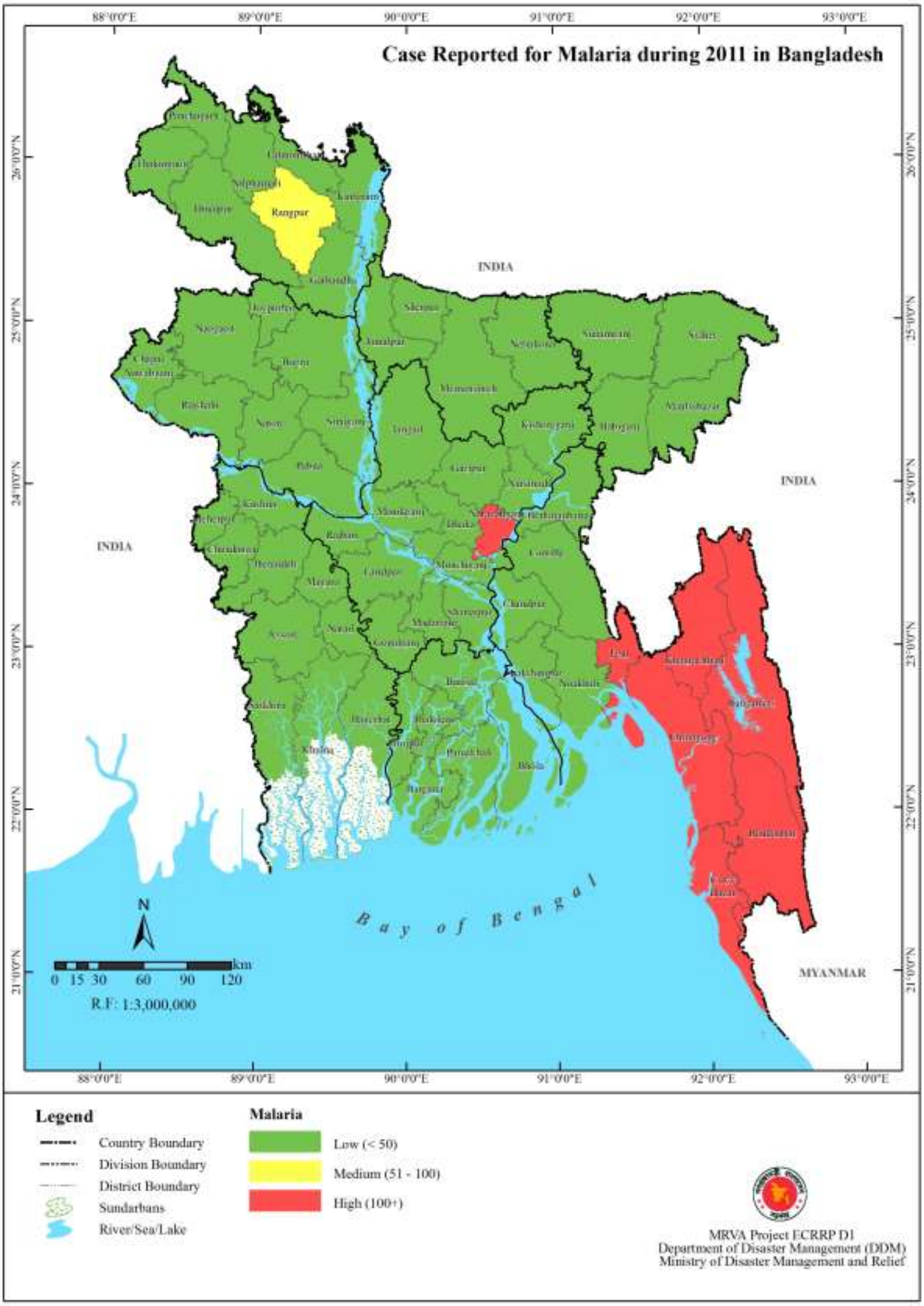


Figure 0.86: Number of cases of Malaria reported in each district in 2011

Source: DGHS, 2013

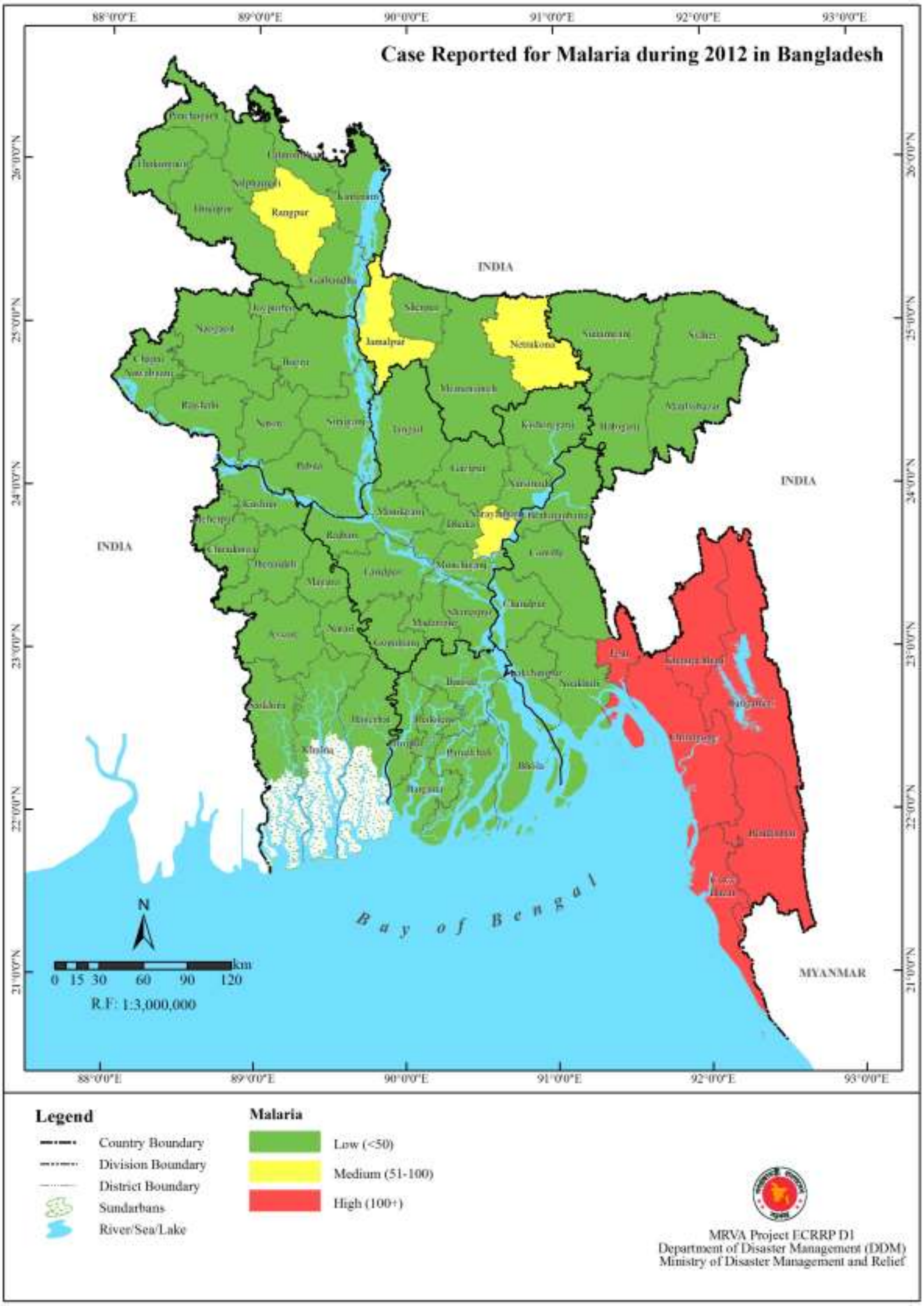


Figure 0.87: Number of cases of Malaria reported in each district in 2012

Source: DGHS, 2013

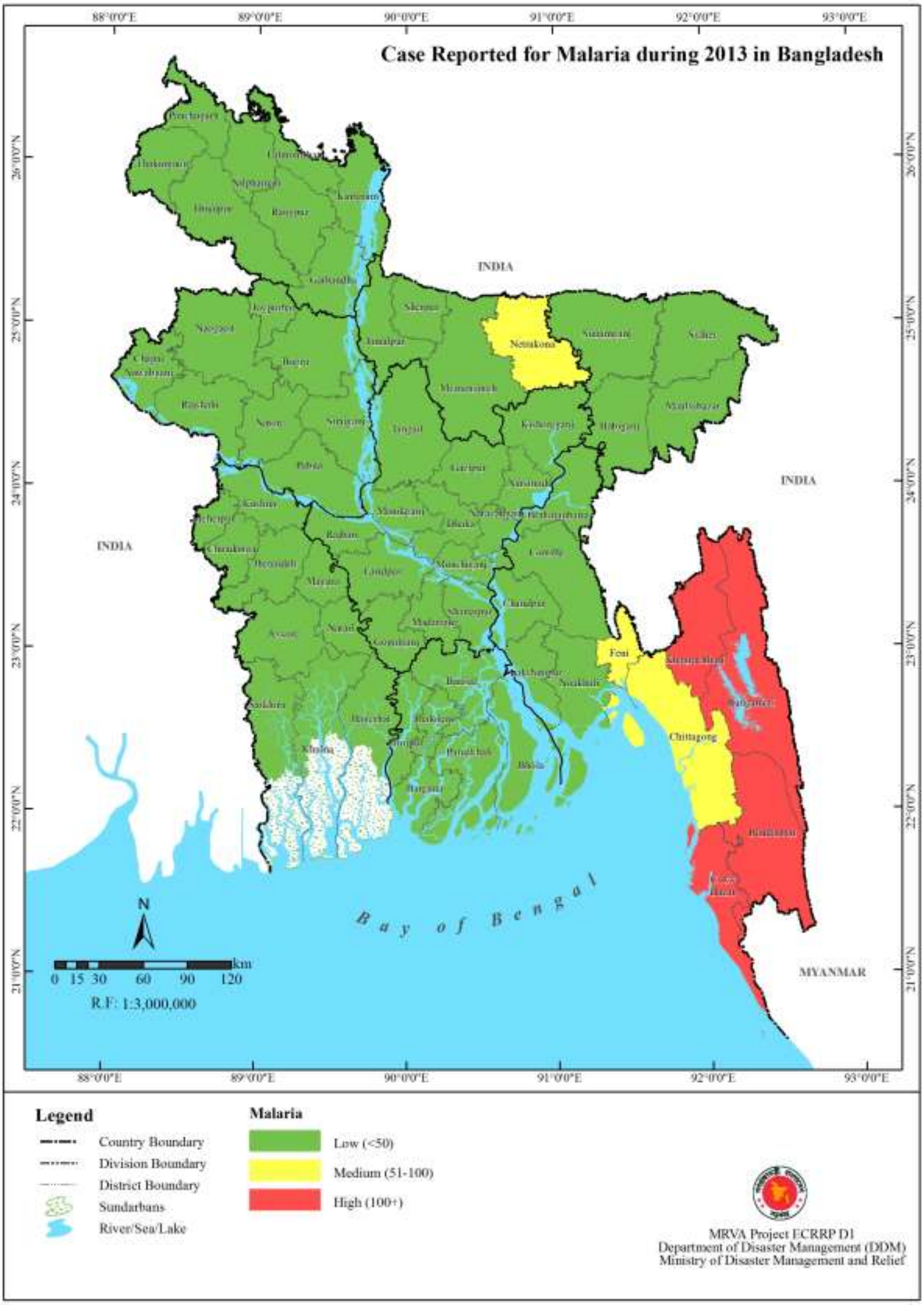


Figure 0.88: Number of cases of Malaria reported in each district in 2013

Source: DGHS, 2013

Tuberculosis (Pulmonary)

The number of reported cases of Tuberculosis (Pulmonary) during 2011, 2012 and 2013 in each division is given in Figure 1.89.

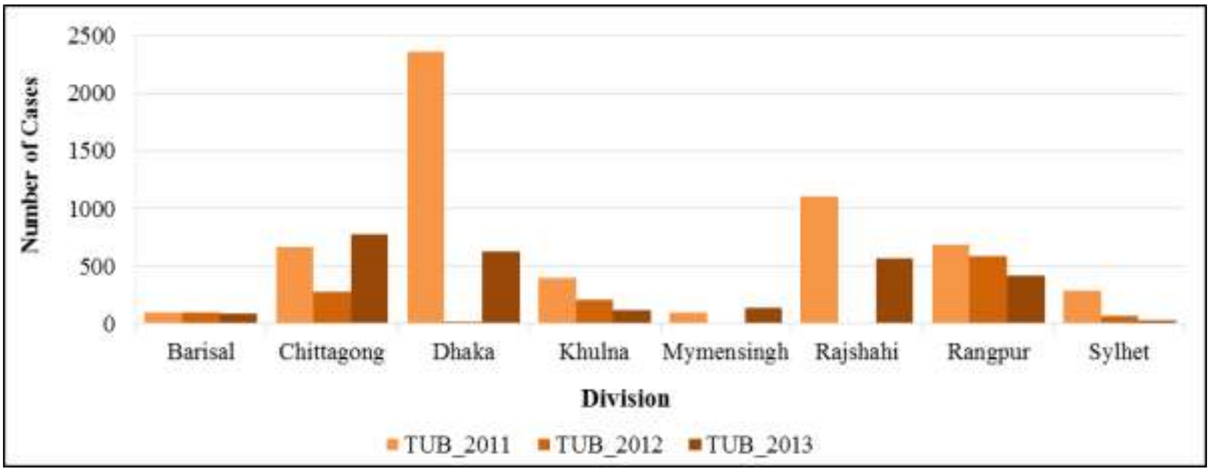


Figure 0.89: Number of cases of Tuberculosis (Pulmonary) reported in 2011, 2012 and 2013 in each division

Source: DGHS, 2013

The highest number of Tuberculosis (Pulmonary) cases reported in 2013 were in Chittagong, Dhaka and Rajshahi divisions. In addition to the total number of cases annually, the number of reported cases on a monthly basis were also analyzed in each division and the radar diagrams of the worst affected divisions in 2013 were Chittagong, Dhaka and Rajshahi, which are shown in Figure 1.90.

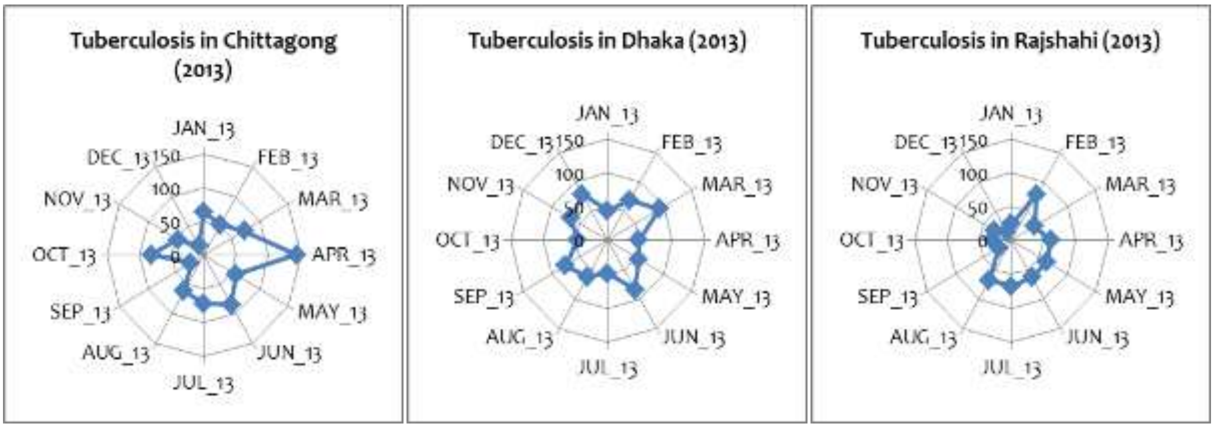


Figure 0.90: Monthly variation of number of reported cases of Tuberculosis (Pulmonary) in most affected divisions

Source: DGHS, 2013

The distribution of the number of cases of Dengue in each district during 2011, 2012 and 2013 is shown in Figures 1.91, 1.92 and 1.93.

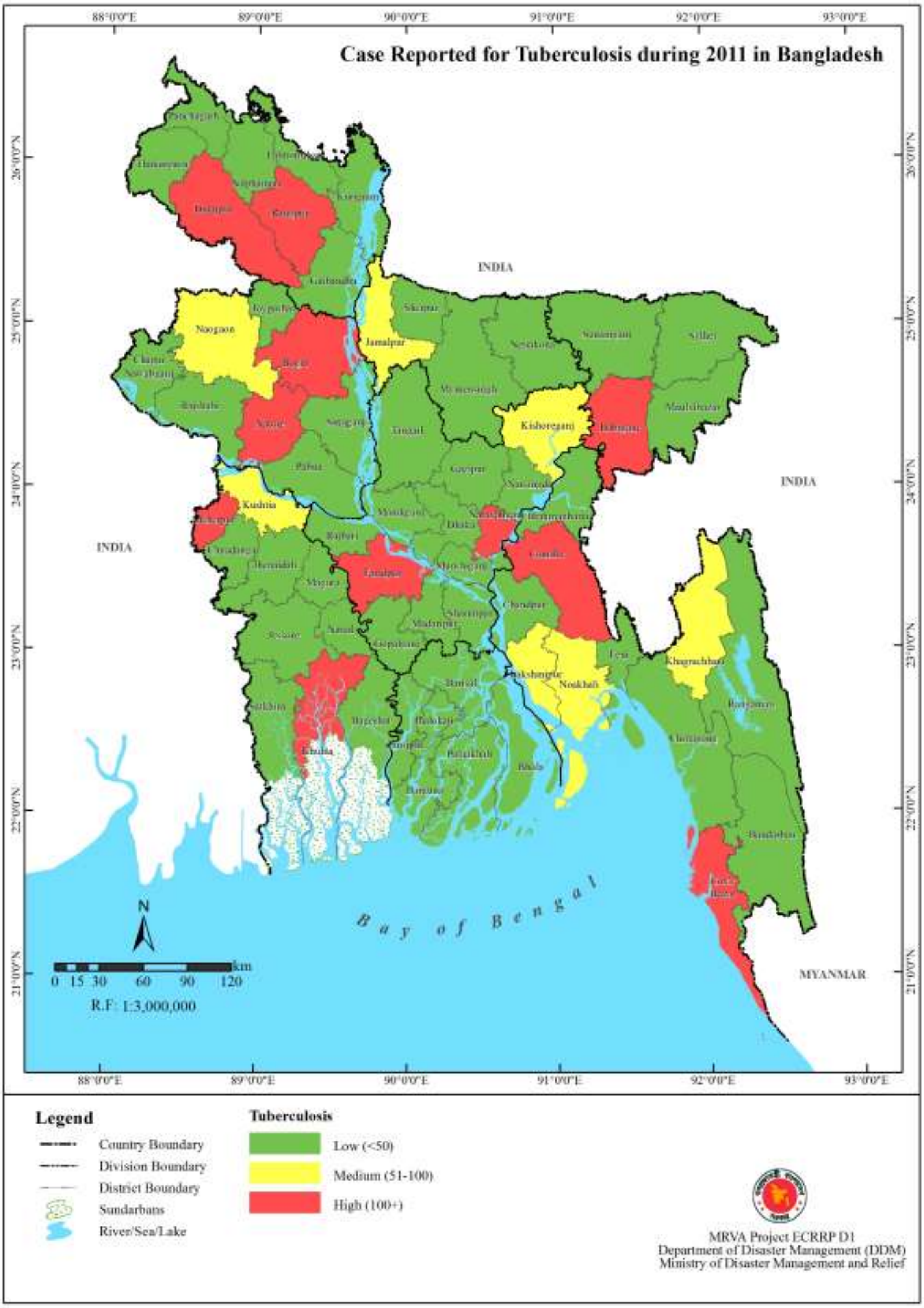


Figure 0.91: Number of cases of Tuberculosis (Pulmonary) reported in each district in 2011

Source: DGHS, 2013

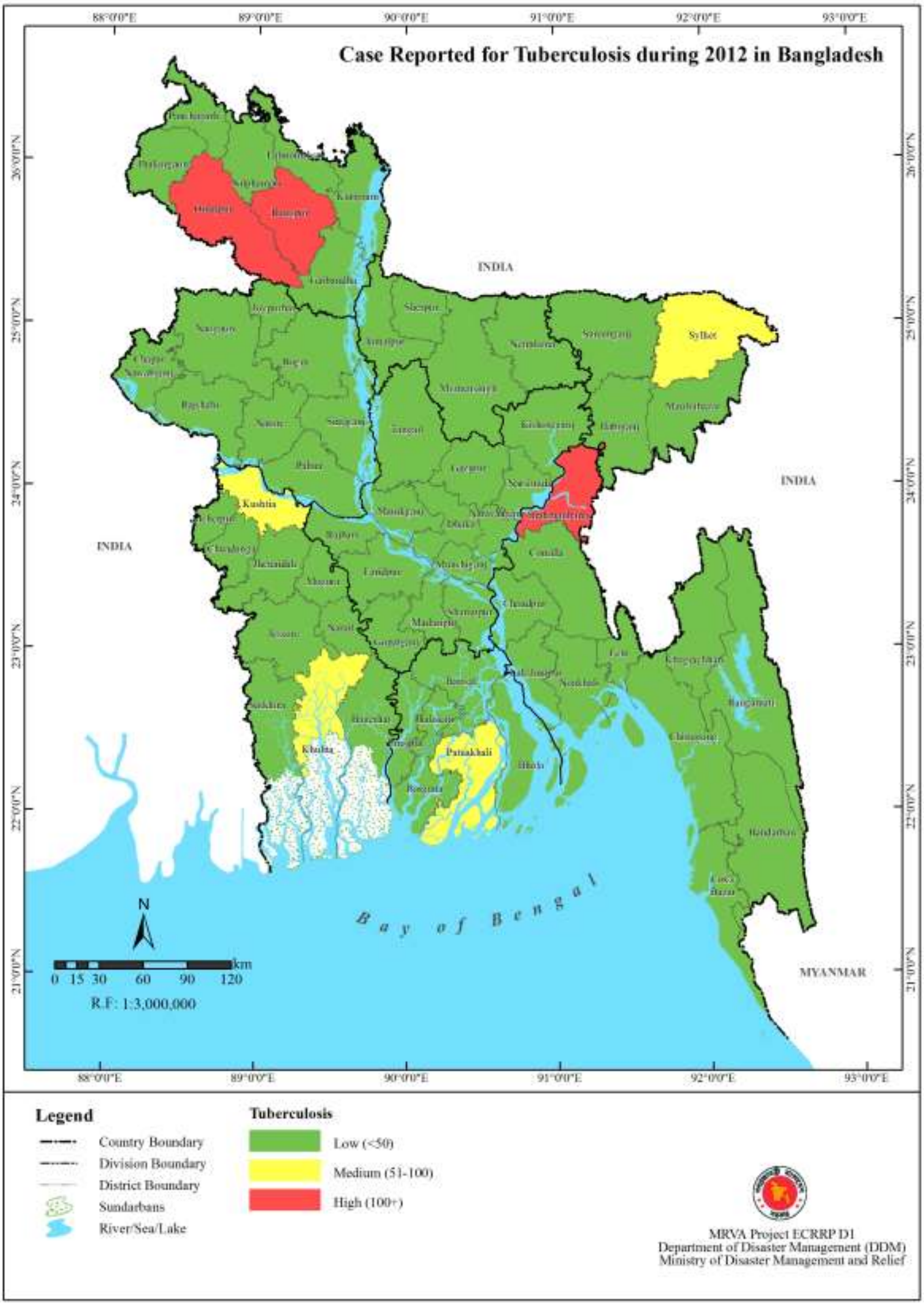


Figure 0.92: Number of cases of Tuberculosis (Pulmonary) reported in each district in 2012

Source: DGHS, 2013

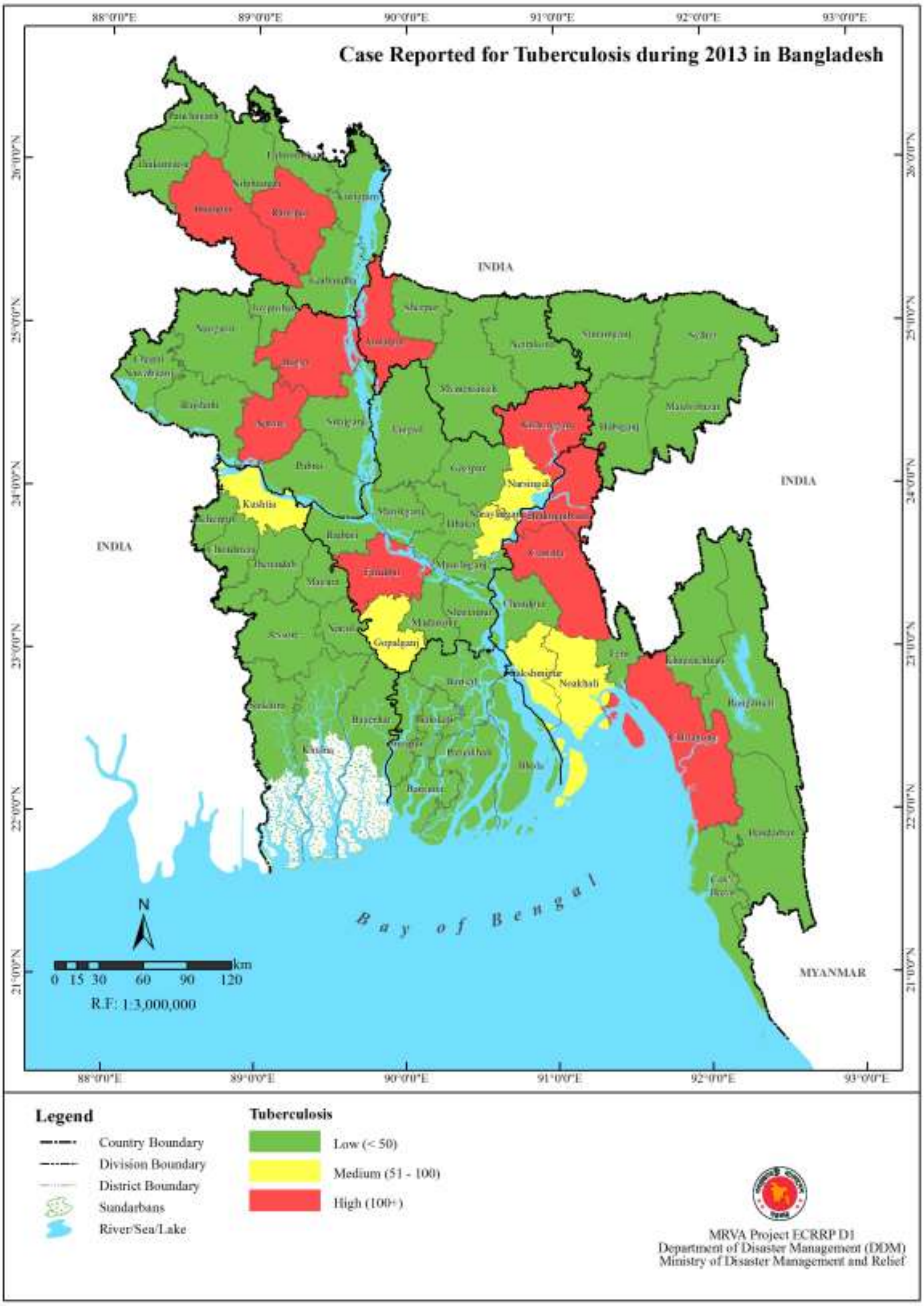


Figure 0.93: Number of cases of Tuberculosis (Pulmonary) reported in each district in 2013

Source: DGHS, 2013

1.5.5 Application of Maps

These maps represent the number of reported persons for each disease for 2011, 2012 and 2013. Analyzing these maps will give the trend of increasing and decreasing number of cases.

In the case of an increasing trend, the maps will help in planning suitable reduction measures in those districts. In the case of a decreasing trend, the maps will provide an opportunity to understand the reasons for improvement and similar attempts can be planned in most affected areas.

An attempt is being made to better understand the reasons for some diseases in the most affected areas due to natural disasters.

1.5.6 Special Remarks

Data was only available at the district level, and therefore analysis at upazila level could not be completed. Efforts should be made to develop a similar database at the upazila level as well.

1.5.7 Recommendations

The analysis was carried out only for seven communicable diseases and arsenicosis, among the 157 diseases for which data was available. Similar methodology may be adopted for analysis of other diseases if necessary.

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