Real - time Urban Flood Forecasting and Disaster Early Warning Spatial Decision Support System using Advanced Technologies for Multilevel Governance

A Case Study of Chennai City




Submitted by

Centre for Disaster Management (CDM)
Lal Bahadur Shastri National Academy of Administration
Mussoorie, Uttarakhand -248179

Submitted to

National Disaster Management Authority (NDMA)
Government of India, New Delhi - 110029

Real-time Urban Flood Forecasting and Disaster Early Warning Spatial Decision Support System using Advanced Technologies for Multilevel Governance

A Case Study of Chennai City

Prepared by

Dr. S. Vijayakumar, IAS*

Additional Chief Secretary, Chairman and Managing Director

Tamil Nadu Urban Infrastructure Financial Service Limited (TNUIFSL), Chennai

Mr. D. Selva Pandian

Vice President, TNUIFSL, Chennai

Mr. R. Pradeep John

Senior Manager, TNUIFSL, Chennai

Dr. A. Jeyaram

Chief Executive Officer, SECON Private Limited, Bangalore

Submitted by

Centre for Disaster Management (CDM)

Lal Bahadur Shastri National Academy of Administration

Mussoorie, Uttarakhand -248179

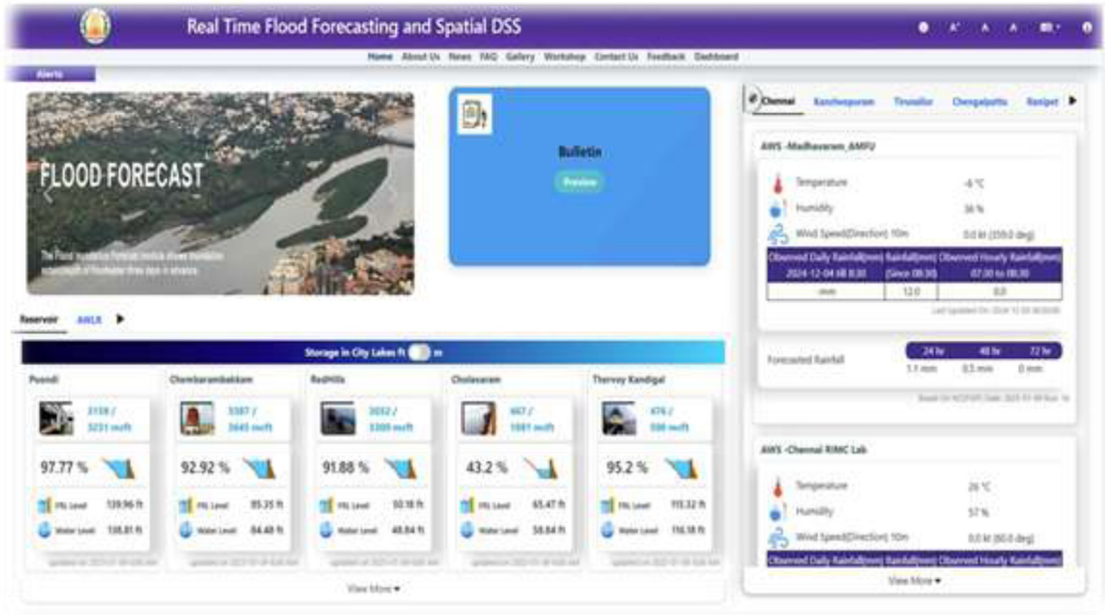
Submitted to

National Disaster Management Authority (NDMA)

Government of India, New Delhi - 110029

Real-time Urban Flood Forecasting and Disaster Early Warning Spatial Decision Support System using Advanced Technologies for Multilevel Governance

A Case Study of Chennai City



Disclaimer

The views expressed in the case study are the outcomes of results obtained from the field study.

Design & Processed by: Greatway Papers, D-54, Dayanand Block, Shakarpur, Delhi-110092
Email: greatwaypapers@gmail.com

Acknowledgements

Real-time Flood Forecast and Spatial Decision Support System for Chennai basin is the product of Government of Tamil Nadu and Tamil Nadu Urban Infrastructure Financial Service Ltd with World Bank financial support. Under the overall guidance of Commissionerate of Revenue Administration, Director - Tamil Nadu Disaster Risk Reduction Agency, Commissioner of GCC, officials of Water Resources Department, Dr. Balaji Narasimhan, Indian Institute of Technology Madras and other stakeholder departments is highly acknowledged during the implementation of the project. Technical support, development of the system and implementation were provided by SECON Private Limited, Bangalore joint venture with JBA, United Kingdom is highly acknowledged.

Dr. S. Vijayakumar, IAS

Additional Chief Secretary, Chairman and Managing Director

Tamil Nadu Urban Infrastructure Financial Service Limited (TNUIFSL), Chennai

Contents

Tables

Figures

Executive Summary

Urban populations are growing rapidly, with projections indicating 68 percent of the world population will live in urban areas by 2050. This growth, combined with the increasing frequency and magnitude of extreme weather events due to climate change, such as storms, cyclones, floods, and earthquakes, exerts significant pressure on urban environments and increases socio-economic risks. Comprehensive Climate Risk Management (CRM) frameworks are essential for reducing climate risks and adapting to climate change. Global best practices in urban flood mitigation have been demonstrated in countries like the Netherlands, Singapore, and Japan.

Chennai Urban area faces increasing flood risk driven by rapid urbanization, climate change, and inadequate drainage infrastructure. This leads to substantial impacts including loss of life, property damage, economic disruption, and long-term social and environmental consequences. Chennai receives an annual normal rainfall of 140cm, with 85cm occurring during the North Eastern monsoon from October to December. The city has experienced catastrophic floods in the past, notably in 2015, which resulted in 422 deaths and economic losses estimated around Rs. 14,602 Crores. Significant transformations have occurred in the Chennai city and basin over the last five decades. The Chennai City Corporation jurisdiction expanded from 174 sq.km in 1978 to 426 sq.km in 2011. From 2001 to 2021, open land and vegetation decreased significantly (70.23% and 4.56% respectively), while the built-up area increased by 56%, largely along key roads. The population of the Greater Chennai Corporation (GCC) rose steeply from 5.8 million in 2001 to 8.9 million in 2011. These factors, combined with climate change risks, exacerbate urban flood risks in Chennai.

Leveraging advancements in computing, high-resolution satellite imagery, IoT devices, and AI-driven analytical tools, the study addresses the complex urban flood risk problems to develop strategies and implement disaster risk reduction practices. Recognizing the past flood disasters in Chennai, the Commissionerate of Revenue Administration, alongside key stakeholders like the Disaster Management Authority, Greater Chennai Corporation, and Water Resource Department of the Government of Tamil Nadu, initiated a project to establish a Real-time Flood Forecasting and Spatial Decision Support System (RTFF & SDSS) in the Chennai basin. Funded by the World Bank and implemented by Tamil Nadu Urban Infrastructure and Financial Service Limited (TNUIFSL), the project aims to set up hydro modelling and monitoring rooms, establish a Real Time Data Acquisition System, develop ensemble rainfall

forecasting, improve hydrologic and hydraulic models, and create a Lake Operation and Guidance System. These components are designed to provide accurate forecasts of rainfall, river flow levels, urban lake inflow/outflow, and street flood inundation. This information drives early warning alerts through a Spatial Decision Support System to assist stakeholders in disaster risk reduction and sustainable mitigation planning. A strategy was also developed to create an institutional model with training and capacity building for stakeholders to enhance climate resilience. The system is capable of interacting with new databases and issuing alerts via web platforms and SMS to users and vulnerable communities.

The study area is the Chennai basin, covering 4974 sq. Km in Tamil Nadu, including parts of Chennai, Kancheepuram, Thiruvallur, Chengalpattu, and Ranipet districts. It is drained by the Adyar, Cooum, and Kosasthalayar Rivers, which flow into the Bay of Bengal, connected by the man-made Buckingham canal. The basin includes the Greater Chennai Corporation area, Chennai Metropolitan Area, and surrounding rural areas. Key water sources include four major reservoirs (Poondi, Red Hills, Cholavaram, and Chembarambakkam) and 1304 tanks. The basin is divided into four sub-basins: Kosasthalayar, Cooum, Adyar, and Kovalam. Physiographically, Chennai is marked by sandy beaches, river mouths, creeks, mangroves, and deltaic regions. The coastline experiences erosion and accretion, and rapid urban sprawl onto former rural lands, water bodies, and wetlands has significantly altered the landscape and drainage patterns. Demographically, Chennai has grown through migration and industrialization, becoming increasingly cosmopolitan. Climatically, it has a tropical climate with hot summers and the North-East monsoon. Urbanization contributes to the urban heat island effect, and the city is prone to flooding during the monsoon, especially around rivers. Chennai has also faced severe water scarcity issues due to over-extraction, such as the crisis in 2019. Sea-level rise and coastal erosion are prominent due to climate change and urbanization, increasing risks from cyclones and storm surges.

The overall approach involved developing a comprehensive framework. This included generating a primary and secondary data knowledge base using high-resolution satellite data and bathymetry surveys, developing improved rainfall forecasts, setting up a Real Time Data Acquisition System (RTDAS) with IoT devices, establishing flood monitoring rooms, developing a web GIS and Spatial Decision Support System (SDSS), and creating hydrologic and hydraulic simulation models (1D, 2D, coupled). Extensive bathymetry surveys of water bodies, waterways, and storm water drains were conducted. High-resolution stereo satellite

data (Cartosat-1, Worldview) were procured and processed to generate Digital Elevation Models (DTM) and Digital Surface Models (DSM) for modelling. Primary survey data on water bodies, waterways, lakes, and drains were integrated with satellite data to create a comprehensive DTM. An Integrated GIS Database was built using primary field surveys, secondary data from various departments, and ortho-rectified satellite data. This database includes administrative, topographic, basin, meteorological, hydrologic, hydraulic, utility, RTDAS, and socio-economic layers. Ensemble Rainfall Forecasting utilizes products from ECMWF and NCEP-GFS for up to 72 hours in advance. Processing accounts for spatial uncertainties, generating percentile values; the 75th percentile forecast is primarily used in hydrodynamic models due to its higher correlation with observed rainfall in the basin.

The Real-Time Data Acquisition System (RTDAS) is a crucial component for providing real-time, accurate data for forecasting and management. An RTDAS network was designed to collect real-time hydro-meteorological and hydrology data across the basin and transmit it via telemetry to hydro-modelling and monitoring facilities. The network includes Automatic Rain Gauges (ARG), soil moisture sensors, Automatic Weather Stations (AWS), Radar-based Automatic Water Level Recorders (AWLR-Radar), Shaft Encoder-based Automatic Water Level Recorders (AWLR-Shaft Encoder), and gate sensors at critical sites. 78 ARGs, 14 AWSs, 61 AWLR-Radar, 80 AWLR-Shaft Encoder, and 42 Gate sensors are being installed. Data is transmitted via GSM/GPRS and L-band satellite telemetry.

Based on the basin's hydrological behavior, Hydrologic and Hydraulic Forecast Models were conceptualized and built. Models simulate the behavior of the Adyar, Cooum, and Kosasthalayar rivers, lakes, tanks, canals, and drainage networks. They integrate a wide range of data including basin boundaries, drainage networks, lake Area-Elevation-Capacity, RTDAS data, terrain models, cross-sections, and climatic data. Models (1D, 2D, and coupled) were systematically set up and calibrated using field observed data to accurately simulate hydrology across different rainfall conditions. Forecasts of water levels in rivers, lake inflow/outflow, and street flood inundation are simulated 72 hours in advance and updated every 6 hours. The Spatial Decision Support System analyzes these outputs, identifies levels above thresholds, and generates flood alert bulletins for stakeholders.

The Lake Operational and Guidance System (LOGS), developed under the project, provides timely inflow forecasts for lake operators. It defines water storage zones (Disaster, Danger, Warning, Alert, Normal, Dead storage) for major lakes. Using radar-based AWLR data and

hydraulic lake models, LOGS simulates inflow, water levels, and storage. A 1D/2D coupled model with LOGS tracks rainfall forecasts and assesses potential inflow to help regulate releases timely and gradually, minimizing downstream flood damages while conserving water. LOGS is implemented in major lakes like Chembarambakkam, Poondi, Redhills, and Cholavaram. Analytical tools in LOGS estimate inflow and provide quantitative information on water release amounts based on forecasted rainfall intensity and available lead time. LOGS has been operational since 2021 and has enabled pre-release of water prior to extreme events during the Northeast Monsoon of 2022, 2023, and 2024, successfully conserving water for drinking supply.

A Web Based Spatial Decision Support System (RTFF & SDSS) has been designed and developed as the central hub. It combines GIS capabilities with decision support tools, storing and managing the organized database, providing visualization, complex queries, analytics, report generation, and alerts/bulletins. Key modules include Login, GIS, RTDAS, Forecast, Lake Operation, Knowledge Base, Bulletin, Information Dissemination, and User & Role - Administration. The RTDAS module fetches real-time data from field instruments for forecasting, validation, and calibration. The system automates the preparation and dissemination of alerts and bulletins based on model outputs, providing readymade maps and tables to decision-makers daily or multiple times a day during critical periods. The Forecast module provides 72-hour forecasts for rainfall, lake inflow/water levels, river water levels at 32 points, and street flood inundation extent/depth/duration. A smartphone crowdsourcing mobile application has also been developed to collect field data (geo-tagged images/videos of inundation) for model validation and improvement. The system is accessible at https://www.chennaifloodsdss.in.

An Early Warning System (EWS) is integrated into the web-enabled RTFF & SDSS. It follows a four-element framework: Disaster risk knowledge (using the comprehensive database for hazard and vulnerability analysis), monitoring and forecasting (RTDAS and models identify precursors and forecast future conditions), warning dissemination (alerts generated based on thresholds), and response capabilities (facilitating timely mitigation actions). The SDSS synthesizes forecasts, identifies risks, and prepares alert bulletins for stakeholders.

Flood prevention and mitigation measures for Chennai Basin were studied systematically, analyzing topography, hydrology, past flood events, modelling results, urban flooding scenarios (including impacts of reservoir releases, encroachments, structural hydraulics, and

the Pallikaranai Marshland), and climate risk factors. Based on this comprehensive understanding and modelling, 34 structural mitigation measures have been proposed and are being examined by the Government of Tamil Nadu for potential implementation.

Institutionalizing the RTFF & Spatial DSS involved studying the existing disaster risk management communication system. The Commissionerate of Revenue Administration (CRA) holds primary responsibility for flood forecasting, preparedness, information dissemination, and relief. The Water Resources Department (WRD) is designated to own and operate the RTFF & SDSS for sustainability, with support from the Chennai Metropolitan Area (CMA). Capacity building and training programs were conducted for officials from various stakeholder agencies (CRA, TNDRRA, WRD, GCC, CMWSSB, CMA, CMDA) covering data collection, remote sensing/GIS, model building/simulation, LOGS, forecasting, and alert dissemination. Hydro modelling control rooms have been established at the State Emergency Operation Centre (SEOC) and flood monitoring rooms at the Collectorates of Thiruvellur, Kanchipuram, Chengalpet, and Ranipet districts. The system operationalizes flood regulation and LOGS based on latest technologies, supplementing older operational rules. Information, Education and Communication (IEC) activities are well-established.

The RTFF & SDSS offers significant Benefits. It provides a comprehensive GIS database for planning and analysis. RTDAS ensures continuous hydro-meteorological data for model refinement and research. Control rooms enable timely issuance of alerts and directions to district administrators. Model outputs provide reliable forecasts for lake, tank, and river levels, assisting water managers in timely operations and minimizing damages. Flood alerts reach the public without delay. Rainfall and lake inflow forecasts aid WRD in deciding when and how much water to release. TNDRRA/CRA can mobilize resources effectively. Street inundation forecasts guide GCC in de-watering efforts. Revenue Department/Collectors can mobilize resources and plan evacuations and shelters. CMWSSB can conserve drinking water through optimized lake regulations. The Education department can issue alerts and prepare schools as shelters.

In Conclusion, the Real-time flood forecasting and spatial decision support system has been successfully implemented and operational since the Northeast monsoon of 2021. It benefits a wide range of stakeholders within the Government of Tamil Nadu, including those responsible for revenue administration, disaster risk reduction, water resources management, urban planning, municipal services, water supply, sewerage, fire/police/public health services, and

education. Stakeholders actively participated in its implementation. The system not only provides early warning but also contributes to reducing economic losses through effective planning inputs. Its sustainability is ensured by active stakeholder involvement, proving to be an effective decision-making tool. The Real-time forecast and Spatial Decision Support System is also being expanded to other river basins of Tamil Nadu.

Centre for Disaster Management

Centre for Disaster Management (CDM) is a research and training centre of Lal Bahadur Shastri National Academy of Administration (LBSNAA), Mussoorie, Department of Personnel & Training (DoPT), Government of India. The Centre is involved in training officers belonging to the IAS and other Group-A civil services at induction as well as at Mid-Career level in various aspects of disaster management through classroom sessions, case studies, and experience sharing presentations, panel discussions, workshops, and mock drills. Apart from conducting training programmes on fire safety, search and rescue, IRS, DRR, DDMP, school safety, the centre is involved in various types of documentation and publication activities in terms of case studies, documentation of best practices, research papers, books and posters in national and international journals and developed course specific training materials in the area of Disaster and Emergency management and Science and Technology.

Centre for Disaster Management (CDM)

Lal Bahadur Shastri National Academy of Administration (LBSNAA),
Mussoorie - 248179, Uttarakhand
EPABX: 0135-2222000 (Extn-2385)
Telephone: 0135-2632655; Fax: 0135-2632350, 2632720
Email: cdm.lbsnaa@nic.in

Design & Processed by: Greatway Papers, D-54, Dayanand Block, Shakarpur, Delhi-110092
Email: greatwaypapers@gmail.com