Indian Meteorological Society, Chennai Chapter Newsletter

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From the Chairman's Desk……

Dear members of IMS Chennai Chapter and readers of BREEZE,

At the first instance, I wish the members of this chapter and readers of this newsletter a safe and comfortable living, free from the COVID-19 pandemic by meticulously following the periodic guidelines issued by various Government agencies and World Health Organisation.

The tenure of the local council of our chapter was over about a year back and as communicated in the previous newsletter we were supposed to elect new local council during May 2020 itself. In view of restrictions on physical gathering / meeting etc due to the ongoing and current COVID-19 pandemic, conducting scientific symposium / seminar / meetings etc. have come to grinding halt throughout the world – albeit some institutions / societies / bodies conducted webinar(s) to sustain the scientific tempo and/or as a survival activity, as the case may be - and we are no exception. We could not succeed, due to multifarious reasons, in our best efforts to conduct the annual general body meeting as well as the online selection / election as an alternative process to elect the chapter's new council. We hope that normalcy will soon be restored so that new council will be elected to continue and carry forward the chapter's routine activities.

In regard to the chapter's activities since the last issue of *Breeze*, I feel sorry to state that we could not arrange scientific lectures / seminars owing to reasons stated above in the prevailing COVID-19 pandemic restrictions. However, the chapter's usual seminar on Review of Monsoons of the previous year was held by way of a webinar on 23rd March 2021 commemorating with the World Meteorological Day function by combining both these activities, this year, into a single event.

Two new members have joined chapter and we welcome them.

The current issue of BREEZE contains scientific / technical notes from members which may interest the readers.

With best regards & Bye
R. Suresh, Chairman, IMS Chennai Chapter, Chennai
Dated: 3 May 2021

Life Membership details of IMS Chennai Chapter (as on 01.05.2021) : 154
The members list is available in
http://www.imdchennai.gov.in/IMSWEB/imsimd/ims_imd.html

INDIAN METEOROLOGICAL SOCIETY
CHENNAI CHAPTER

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Rapid Mode Transmission in Moored Data Buoys During Cyclones

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ABSTRACT

The moored buoy network in North Indian Ocean is operational for more than two decades, which is established with a primary objective to support cyclone early warning services. The program has grown up in leaps and bounds both in quantity and quality by providing crucial met-ocean observations in real-time, particularly during extreme events. Significant technological advances are accomplished along with indigenizing efforts. One of the significant improvements in the buoy system is the facility for rapid mode transmission during the passage of a cyclone. The rapid mode transmission successfully triggered during many cyclones and provided high frequency real-time data sets, which is appreciated by regional and global scientific community.

Keywords: Cyclone, Rapid transmission, Moored data buoys, North Indian Ocean

INTRODUCTION

Indian Ocean, the smallest among the major oceanic basins exhibits many unique features contributed by its limited northward extent and monsoon systems, which adds to its complex nature. The Indian Ocean was significantly under sampled, till about two decades ago, when compared to other tropical oceans of the world. The inception of the moored buoy program by National Institute of Ocean Technology (NIOT) under the aegis of Ministry of Earth Sciences (erstwhile Department of Ocean Development) earmarked a new era of systematic collection of meteorological and oceanographic parameters in the North Indian Ocean. The moored buoys are fitted with a set of meteorological and oceanographic sensors that measure data up to 500m below the sea surface and transmit real-time data to the data reception centre at NIOT at every three hours (Venkatesan et. al., 2013).

The buoy network programme, the first of its kind in Indian Seas, is now operational for more than two decades, transmitting uninterrupted data in real-time despite innumerable challenges (Venkatesan et. al., 2016). The network includes 12 deep ocean OMNI buoys, 4 coastal buoys, one Cal-Val buoy and 2 tsunami buoys (Figure.1) apart from an Arctic buoy and has achieved data return of more than 90 per cent.

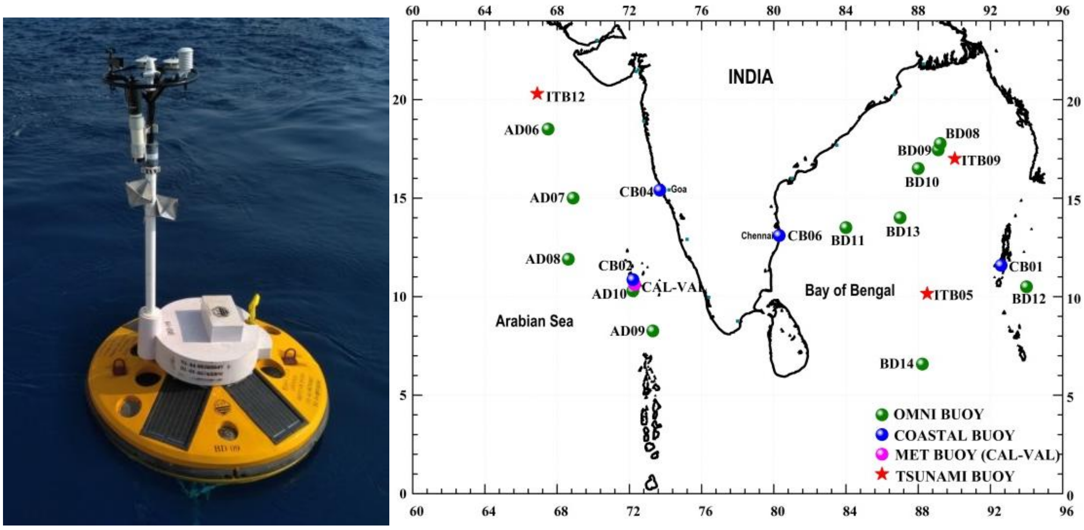

Figure 1. Moored data buoy and the buoy network in North Indian Ocean.

The moored data buoy network is established with a primary objective of capturing the oceanic response during the cyclone passage and thereby to support the better prediction of cyclones. The frequency of cyclones in north Indian Ocean is less compared to that of the major oceanic basins, but is in par with associated loss of life and property. Moreover, the north Indian Ocean witnessed an increase in the frequency and intensity of cyclones in the recent past exposing the densely populated coastal areas under threat. The long term moored buoy measurements of meteorological and oceanographic parameters provided new insights of the ocean dynamics of the North Indian Ocean particularly in better understanding the dynamics during the passage of cyclones (Navaneeth et. al., 2019; Venkatesan et. al., 2014; Vengatesan et. al., 2020). This in turn steered the demand for higher frequency of real time transmission. However, higher transmission rate indicates higher consumption of energy leading to frequent services and higher cost of transmission. An agreeable solution was arrived with higher transmission limited to the crucial period of cyclone passage.

The real time datasets greatly helped the weather forecasts and ocean state forecast by providing the critical information about the remote marine environment. The early warning services utilise the in-situ moored buoy observations particularly the tropical cyclone heat potential in better predicting the cyclone track and intensity. The present study details the development and implementation of the cyclone rapid mode algorithm in the moored buoy network along with two case studies of the successful rapid mode transmission that triggered during the super cyclone Amphan in May 2020 and Very Severe Cyclone Nivar in November 2020.

Development of the algorithm

Buoy measurements during the past cyclones were analysed in detail to identify a suitable method to detect the approaching cyclones and to trigger into rapid mode transmission. Strategically positioned moored data buoys captured the signals of more than 30 low pressure systems in north Indian Ocean during the operational span of more than two decades. It is observed that the buoy locations spread over a large basin with significant seasonality exhibit large variability in meteorological and oceanographic parameters. Moreover, the tropical cyclones also exhibit significant seasonality - before and after the southwest monsoon, which again differs in Arabian Sea and Bay of Bengal. The challenge was to develop an algorithm, which is uniformly applicable in both the basins over the large latitudinal area. It was also a challenge to operate the same algorithm throughout the year without any false trigger.

The detailed analysis of past cyclones revealed that the quickest response is evident in air pressure and in wind speed in which the measurement and processing are also easy compared to that of waves and currents. However, the passage of the eye of the cyclone over the buoy location may not satisfy the expected high wind conditions and hence discarded wind in the further analysis. The algorithm was developed utilising the dynamic threshold with the sudden drop in air pressure triggered by an approaching cyclone (patent filed). This enabled the implementation of the algorithm regardless of spatio-temporal variability at any location and at any point of time.

Implementation of the algorithm in Moored Data Buoys

The moored buoy program at NIOT is also focusing on indigenizing the buoy technology and data acquisition system to facilitate upgradations and to reduce the exorbitant costs of imported systems. Hrudaya, Indigenous buoy Data Acquisition System (I-DAS) has the facility to interface all the buoy sensors, programmable data collection, process, and store and transmitting real time data through satellite to the NIOT data centre. The development of I-DAS has reduced India’s technology dependence and is competitive in cost. Apart from regular meteorological and subsurface data collection, Hrudaya is configured to detect the cyclone events (Venkatesan et. al., 2018). The system enters into rapid transmission mode in the vicinity of a low pressure system and starts transmitting at high frequency. The frequency of rapid mode transmission is scalable to the highest frequency of 30 minutes.

Rapid mode Transmission during Cyclones

The OMNI buoy BD09 (89.1 ^{o} E/17.5^{o} N) in northern Bay of Bengal has recorded the signals of many low pressure systems that formed in Bay of Bengal since its inception in May 2011. The buoy was deployed with facility for rapid transmission in December 2019 and triggered high frequency transmission during the super cyclone Amphan in May 2020 (Fig. 2b). The buoy transmitted data at one hour interval, while the data is transmitted at every 3 hours interval during normal conditions. The high frequency transmission was triggered at 00:00 GMT on 19 May 2020 and continued till 16 GMT on the same day providing 11 additional real-time data sets. BD09 recorded minimum air pressure of 988 hPa on 19 May 12 GMT.

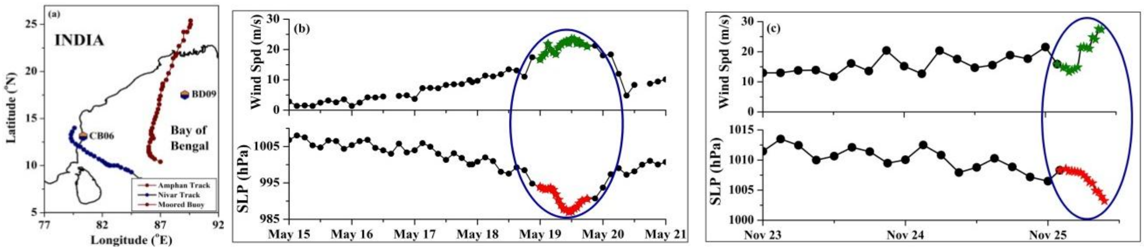

Fig.2:(a) The cyclone tracks and the time series observations of air pressure and wind speed with high frequency real time data during the cyclones b) Amphan and c) Nivar

The refined algorithm with provision for rapid mode algorithm at 30 minute interval (highest frequency) was implemented in the coastal buoy CB06 (80.3 ^{o} E/13.1^{o} N) off Chennai during the deployment in March 2020 (Fig. 2c). The upper ocean response of the Very Severe Cyclonic Storm Nivar was captured by the coastal buoy CB06 located off Chennai and continued till the system made landfall near Puducherry, south of Chennai on 25 November 2020.

The coastal buoy triggered high frequency data transmission as the Very Severe Cyclonic Storm Nivar approached the buoy on 24 November 2020. The buoy transmitted data at 30 minutes interval against the normal transmission rate at three hour. The high frequency transmission was triggered at 23:00 GMT on 24 November 2020 and continued till 09:30 GMT on 25 November by providing 18 additional real-time data sets. The buoy measurements exhibit the extreme sea state associated with the cyclone passage, which recorded maximum wind speed of 100 km/hr accompanied by significant wave height of 6.7 m on 25 November. The minimum sea level pressure recorded is 1004 hPa and the temperature recorded a reduction to 28.0 °C.

The World Meteorological Organization, India Meteorological Department and other service providers appreciated the continuous support of buoy observations, particularly the high frequency observations during Cyclone Amphan.

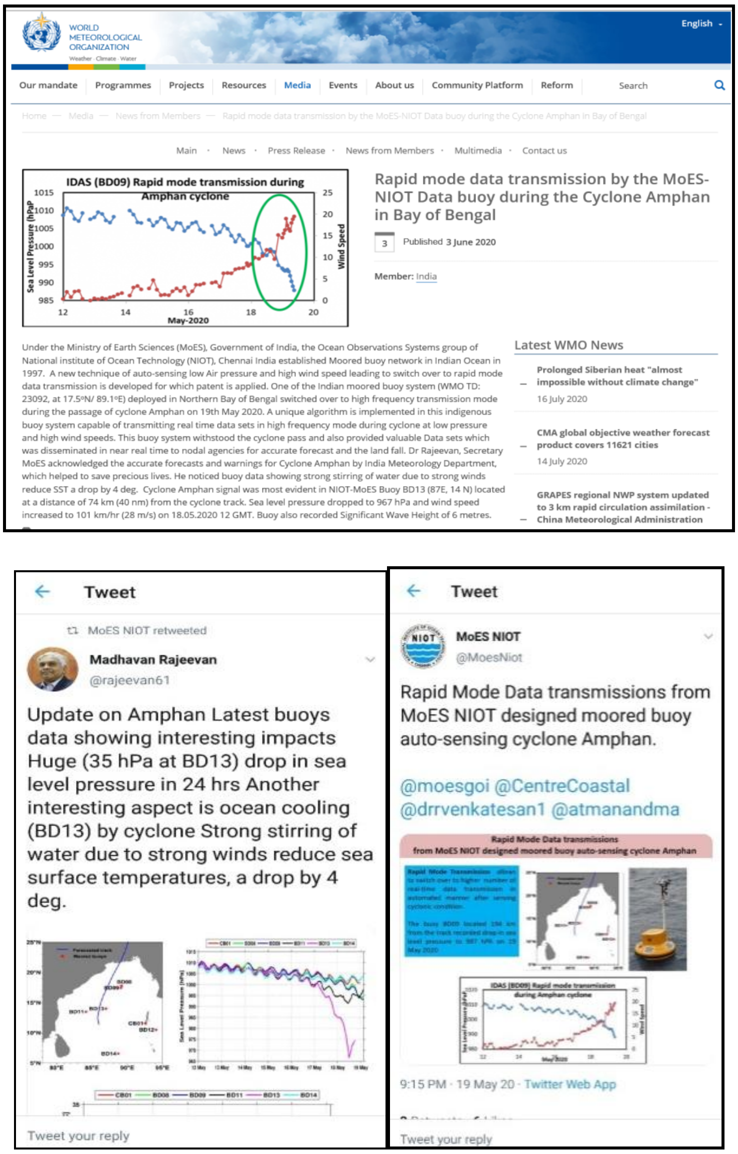

Fig 3.: The appreciation from WMO and secretary MoES for the Rapid Mode Data transmissions from NIOT Indigenous moored buoy during cyclone Amphan

The rapid mode algorithm enabled the buoy system to provide the critical met-ocean datasets to stake holders with higher frequency in real-time. The rapid mode hourly real-time transmission from BD09 buoy (Indigenous OMNI Buoy) during cyclone Amphan was appreciated by World Meteorological Organization (WMO) and was published as newsletter in WMO website (Fig. 3).

Conclusion

The moored buoy network is strategically positioned in the North Indian Ocean to support the cyclone early warning services. The rapid mode algorithm is developed based on the analysis of past moored buoy measurements during cyclones. The algorithm is successfully incorporated in the indigenous data acquisition system in coastal and deep ocean buoys, which was found to be triggering to rapid mode during the passage of cyclones and resuming to normal mode after the passage of cyclones. The availability of critical met-ocean data sets in real-time during cyclone passage is appreciated by World Meteorological Organization, India Meteorological Department and other service providers.

Acknowledgement

The authors thank the Ministry of Earth Sciences (MoES), Govt. of India and Director, NIOT for support and encouragement to carry out this work. We also thank the staff of Ocean Observation Systems (OOS) group for their efforts in sustaining the moored buoy network.

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Mission Mangal
(Mangalyaan, HOPE, Tianwen-1 and Perseverance)

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1. Introduction

In Feb 2021, three spacecrafts from Earth reached planet Mars to look for signs of past life - the UAE's maiden interplanetary mission "Hope Orbiter", China's first Mars mission, "The Tianwen-1 Orbiter" and the USA's complex "Perseverance Rover". All three missions were launched in July 2020 and arrived at the planet in February this year within a space of a few days [(1)].

A primary objective when it comes to launching a spacecraft is to get it to its target destination by consuming minimum fuel. To ensure this, a flight path called the Hohmann Transfer Orbit[(2)] is followed, which is around the Sun and is elliptical in shape, just like planetary orbits. The opportunity to optimally launch and take the spacecraft in the least time to reach Mars, occurs every 26 months or 780 days due to the nature of the orbits of Earth and Mars. Fig. 1 shows Hohmann Transfer Orbit of Mangalyan aka Mars Orbiter Mission (MOM).

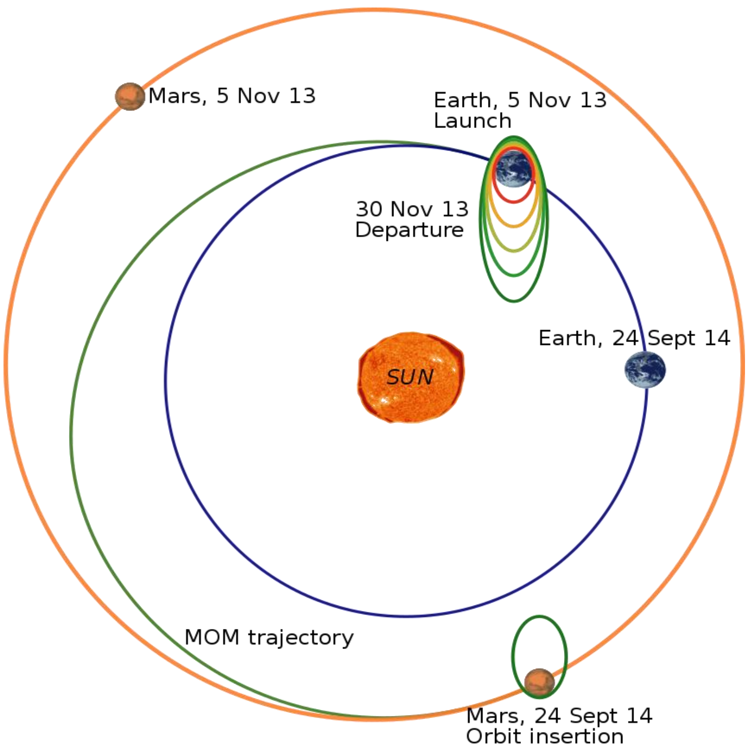

Fig. 1 : Hohmann Transfer Orbit of Mangalyan

India’s Mangalyaan and MAVEN (USA) were launched in November 2013, ExoMars in March 2016, Insight in May 2018, and the latest three missions in July 2020. The first successful mission was Mariner 4 flyby spacecraft of US on 15 July 1965 (3) after five failed missions of USSR and USA. A total of 49 Mars missions have been attempted, with nearly 15 failed missions. The four Missions to Mars, viz. Mangalyaan, HOPE, Tianwen-1 and Perseverance are described in this article.

Mars is the fourth planet from the Sun and the second-smallest planet in the Solar System, being larger than only Mercury. Other details of Mars in comparison with Earth are given below.

DESCRIPTION	EARTH	MARS
Average Distance from Sun	148 million km	225 million km
Average Speed Orbiting around Sun	29 km per second	23.2 km per second
Diameter	12600 km	6600 km
Tilt of Axis	23.5 degrees	25 degrees
Length of Year	365.25 days	687 Earth days
Length of Day	23 hours 56 minutes	24 hours 37 minutes
Gravity	9.3 m / sec2	0.375 of Earth
Temperature	Average + 14 °C	Average - 63 °C
Atmosphere	nitrogen, oxygen, many trace gases	mostly carbon dioxide, some water vapor
Number of Moons	1	2

2. Mangalyaan (India)

On 24 September 2014, the Indian Space Research Organisation (ISRO) became the fourth space agency to visit Mars when its maiden interplanetary mission, the Mars Orbiter Mission (Mangalyaan) spacecraft, arrived in orbit. The United Arab Emirates became the fifth to successfully undertake a mission to Mars, having inserted an orbiter into the Martian atmosphere on 9 February 2021. NASA's *Perseverance* rover successfully landed on Mars on 18 February 2021.

The scientific instruments on Mangalyaan were Mars Colour Camera (MCC), Lyman Alpha Photometer (LAP), Methane Sensor (MSM), Neutral composition Analyser (MENCA) and Thermal IR imaging Spectrometer (TIS). The objectives of the mission were to study the dynamics of the upper atmosphere of Mars, effects of solar wind, surface features by studying the morphology, topography and mineralogy, studying the constituents of Martian atmosphere including methane and CO_2 using remote sensing techniques. More than 30 research publications have resulted from Mangalyaan data. A photo taken by Mars Colour

Camera is shown in Fig 3. See https://www.space.com/23203-india-mars-orbiter-mission-photos.html for some other stunning photos of Mars taken by Mangalyan.

Fig. 2 : Mangalyaan Spacecraft

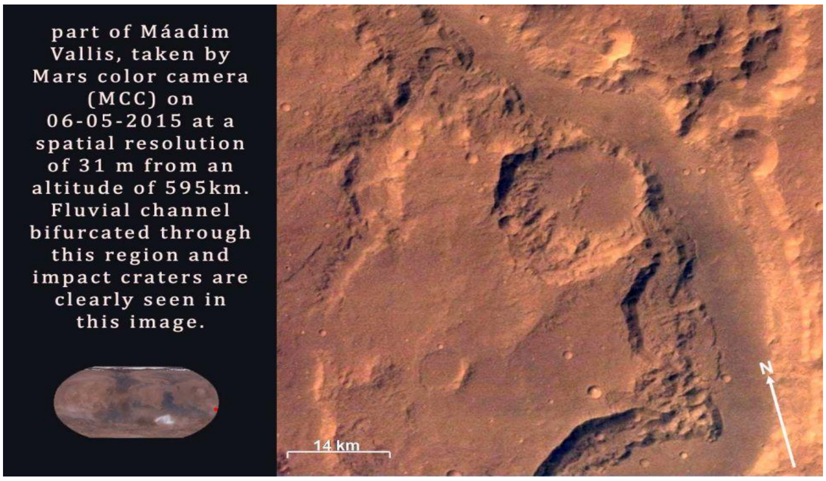

Fig. 3 : A High Resolution Picture of a Fluvial Channel and impact Crater taken by Mangalyaan

3. Recent Mars Missions:

Simultaneously three missions were sent to Mars, viz. a UAE's first interplanetary mission, the Hope Orbiter, China's first Mars mission, the Tianwen-1 Orbiter and the US' complex Perseverance Rover, recently. Brief information on these three missions are presented.

(a) **HOPE (UAE) :** The **Emirates Mars Mission** "HOPE" was launched on 19 July 2020, and reached Mars on 9 February 2021. The mission design, development, and operations are led by the Mohammed bin Rashid Space Centre (MBRSC) and the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder, with support from Arizona State University (ASU) and the University of California, Berkeley. The spacecraft will spend the next two months moving into its final science orbit at altitudes ranging from 20,000 to 43,000 km above the planet. The orbit is designed to allow the spacecraft's instruments to capture full views of the planet's atmosphere every nine days to support studies of Martian weather patterns as well as how gasses in the planet's atmosphere escape to space.

The three main objectives of the Hope probe are:

- Understand the climate dynamics and global weather map of Mars by studying the lower atmosphere of Mars.
- Explain how the weather of Mars affects the escape of hydrogen and oxygen, by correlating conditions in the lower and upper atmosphere
- Understand the presence and variability of hydrogen and oxygen in the upper atmosphere, and why Mars is losing these gases to space.

  Hope will be "the first true weather satellite" at Mars and will provide the first complete picture of the Martian atmosphere and its layers.

(b) **Tianwen 1 (China):** ***Tianwen-1*** is the interplanetary mission by the China National Space Administration (CNSA) to send a robotic spacecraft to Mars, consisting of an orbiter, deployable camera, lander and rover. The spacecraft, with a total mass of nearly five tons, is one of the heaviest probes launched to Mars and carries 13 scientific instruments. The mission was successfully launched from the Wenchang Spacecraft Launch site on 23 July 2020 on a Long March 5 heavy-lift launch vehicle. After seven months of transit, it entered orbit around Mars on 10 February 2021. For the next 2 months the space probe will study the target site from a reconnaissance orbit, then in May or June 2021 the landing is planned to begin with the release of the capsule. It is projected to make an atmospheric entry followed by a descent phase under parachute, after which the lander will use its propulsion to land smoothly on Mars. If all goes according to plan, the lander will then deploy the rover designed to explore the surface for 90 Martian days. The orbiter will serve as a telecommunications relay during the rover's primary mission and will position itself in an orbit more conducive to observations while retaining its role of relay.

This is China's first successful interplanetary mission, as well as its first independent probe to Mars. From a scientific point of view, the mission has five objectives:

- Study the morphology and geological structure of Mars, as well as its evolution and its causes. The two cameras present on the orbiter are dedicated to this objective.

- Study the characteristics of the surface and underground layers of the soil of Mars, as well as the distribution of water ice. This is the role of the radars present on the orbiter and the rover.
- Study the composition and type of rocks as well as the minerals and elements present on the surface of Mars. The spectrometers on board the orbiter and the rover as well as the multispectral camera are dedicated to this objective.
- Study the ionosphere, the climate, the seasons and more generally the atmosphere of Mars, both in its near space environment and on its surface. This is the role of the two particle detectors present on the orbiter as well as of the rover's weather station.
- Study the internal structure of Mars, its magnetic field, the history of its geological evolution, the internal distribution of its mass and its gravitational field. The magnetometers as well as the radars present on the orbiter and the rover are dedicated to this objective.

The aims of the mission include searching for evidence of current and past life, producing surface maps, characterizing soil composition and water ice distribution, and examining the Martian atmosphere, and in particular its ionosphere.

The mission also serves as a technology demonstration that will be needed for an anticipated Chinese Mars sample-return mission proposed for the 2030s. *Tianwen-1* will also cache rock and soil samples for retrieval by the later sample-return mission.

(c) Perseverance Mission (USA): ***Perseverance***, nicknamed ***Percy,*** is a car-sized Mars rover designed to explore the crater Jezero on Mars as part of NASA's Mars 2020 mission. It was manufactured by the Jet Propulsion Laboratory and launched on 30 July 2020. Confirmation that the rover successfully landed on Mars was received on 18 February 2021. Following the rover's arrival, NASA named the landing site Octavia E. Butler Landing. *Perseverance* has a similar design to its predecessor rover, *Curiosity,* from which it was moderately upgraded. It carries seven primary payload instruments, 19 cameras, and two microphones. The rover is also carrying the mini-helicopter *Ingenuity*, or *Ginny*, an experimental aircraft and technology showcase that will attempt the first powered flight on another planet. The rover's goals include identifying ancient Martian environments capable of supporting life, seeking out evidence of former microbial life existing in those environments, collecting rock and soil samples to store on the Martian surface, and testing oxygen production from the Martian atmosphere to prepare for future crewed missions.

The *Perseverance* rover has four science objectives that support the Mars Exploration Program's science goals:

- Identify past environments that were capable of supporting microbial life
- Seeking biosignatures: seek signs of possible past microbial life in those habitable environments, particularly in specific rock types known to preserve signs over time
- Caching samples: collect core rock and regolith samples and store them on the Martian surface
- Preparing for humans: test oxygen production from the Martian atmosphere.

4. Recent Status & Results :

HOPE : HOPE has collected first series of images from an orbit altitude of 36,000 km, The images show the measured signal from scattered sunlight off hydrogen and oxygen and emission from carbon monoxide in the Mars thermosphere, produced by the breakdown of water and carbon dioxide in the atmosphere. The images taken are useful to study global characteristics and variability of hydrogen and oxygen in the Mars upper atmosphere, right at the edge of space.

Tianwen 1 : The lander carrying the rover is expected to land on Mars in May or June of this year. .Chinese space scientists have chosen a relatively flat region in the southern part of Utopia Planitia, a large plain, as a potential landing zone.The rover will be released after landing to conduct scientific exploration,. Meanwhile it has captured many stunning images of Mars.

Perseverence : Perseverence successfully landed on Mars on 18th February. The mission touched down within five meters of their landing target (the landing target that was chosen by the terrain relative navigation system, not the pre-planned estimation), and several minutes later sent its first image of the Martian surface back to Earth. It is presently moving around Mars surface taking Photos and sending them.

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Salient Features of Northeast Monsoon 2020

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The Indian southwest monsoon (SWM) season of June to September is the chief rainy season for India and about 75% of the country's annual rainfall is realised during this season. Subsequent to the withdrawal of SWM, the northeast monsoon (NEM), a small scale monsoon confined to parts of southern peninsular India comprising of the meteorological sub-divisions of Tamil Nadu, Puducherry &Karaikal (TN), Kerala &Mahe(KER), Coastal Andhra Pradesh &Yanam(CAP), Rayalaseema (RYS) and South Interior Karnataka (SIK) occurs. For the subdivision of TN, the normal SWM seasonal rainfall realised is only about 35% (342.0 mm) of its annual rainfall (914.4 mm)as this subdivision comes under the rain-shadow region during theSWM. The northeast monsoon (NEM) season of October to December (OND) is the chief rainy season for this subdivision with 48% (447.4 mm) of its annual rainfall realised during this season and hence its performance is a key factor for this regional agricultural activities.

Further, the NEM season is also the primary cyclone season for the North Indian Ocean (NIO) basin comprising of the Bay of Bengal (BOB) and the Arabian Sea (AS) and cyclonic disturbances (CDs; low pressure systems (LPS) with maximum sustained surface wind speed (MSW) of 17 knots or more) forming over BOB and moving west/northwest-wards affect the coastal areas of southeastern peninsular India and also contribute significantly to NEM rainfall.

Prior to the commencement of NEM rains, after the withdrawal of SWM upto 15°N, reversal of low level winds from southwesterly to northeasterly occurs. The normal date of setting in of easterlies over the southeastern peninsular India is 14thOctober. The normal date of onset of NEM over Coastal TN (CTN) and south CAP is 20thOctober.The normal rainfall received over the five NEM sub-divisions during OND is TN-447.4 mm, KER-491.6 mm, CAP-338.1 mm, RYS-223.3 mm and SIK-204.1 mm. However, the NEM seasonal rainfall shows a high degree of variability with 27% co-efficient of variation.

The NEM rainfall is influenced by global climate parameters such as ENSO (El Nino/La Nina & Southern Oscillation Index), Indian Ocean Dipole (IOD) and Madden-Julian Oscillation (MJO). El Nino, positive IOD and MJO in phase 2-4 with amplitude greater than one are generally associated with good NEM rainfall.

During October-December 2020, La Nina and positive Southern Oscillation Index prevailed over the equatorial Pacific which was not favourable for good NEM activity during the first half of the season, but, was favourable during the later half of the season. IOD was neutral and indicated normal seasonal rainfall. MJO was in the western hemisphere (phase 5-7)during October and hence was not favourable to NEM activity. In November and December, it was favourableon about 50-55% and 35% of days during the month respectively.

Under this climate setting, the withdrawal of SWM 2020 upto 15°N took place only 27th October due to extended SWM conditions. The SWM 2020 withdrew from the entire country on 28th October and NEM rains commenced simultaneously on 28th October 2020 under the influence of a cyclonic circulation off the south CAP & TN coast and northeasterly winds over coastal TN.

Subsequently under the influence of passage of troughs in low level easterlies and two tropical cyclones over the BOB - VSCS Nivar (22-26 Nov 2020) that crossed coast near Puducherry on 25 November & CS Burevi that came close to Pamban 03 December, the NEM activity picked up and by the end of the season, excepting KER, all the subdivisions benefitted by the NEM had received normal to excess rainfall. CAP and RYS recorded +24% and +54% excess rainfall respectively, TN & SIK, normal rainfall (+6% &+0% respectively). Only KER came under deficient category (-26%).

Further, the NEM activity extended into the first half of January 2021. Subsequently, cessation of NEM rains over the Indian region occurred on 19th January 2021.

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Rainfall Distribution over Chennai on Historic Rainy Day in 2015

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Introduction

Rainfall is one of the meteorological phenomena that have the greatest impact on human activities and the most important environmental factor limiting the development of the semiarid regions. Rainfall is an important natural source of water in any place on the earth. The amount or availability of water for various purposes is very much depending upon the amount of precipitation in that particular area. Excess or extended absence of rainfall could cause flooding or drought respectively. Floods refer to huge amount of water reaching land in a short span of time, causing land surface to be submerged under water – at places, where, the land surface is usually not covered with water.

Floods could be caused due to natural causes, or human activities, or a combination of both. Floods are caused by discharge of huge volume of water in a short span of time, at such a rate that the water cannot be carried away from the scene of discharge. Extreme rainfall events may only last for a few hours at the most, but can generate terrifying and destructive floods. Their impact can be affected by a wide range of factors such as the location and intensity of the rainfall, the shape and steepness of the catchment it falls on, how much sediment is moved by the water and the vulnerability of the communities in the flood's path.

In recent years, heavy precipitation events have resulted in several damaging floods in India. The flash floods that occurred over three major metro cities in the same year 2005 i.e. Mumbai in July, Chennai in October and December, and Bangalore in October in addition the Chennai rains of December 2015 caused extensive damage to human lives and property. Thus rainfall plays a crucial role in the economic development of any country and India is one of the highly flood prone countries in the world. Around 40 million hectares of land in India is prone to floods as per National Flood Commission report. Northeast Monsoon - 2015 was so special in Chennai and in Tamil Nadu where consistent and copious rainfall brought widespread flood along the coastal districts namely Chennai, Kancheepuram, Thiruvallur, and Cuddalore. Understanding the rainfall distribution pattern really helps the disaster management team to plan in advance and act proactively to minimize the loss to human lives and reduce the impact on properties.

An attempt has been made using rainfall data of the year 2015, to spatially interpolate the rainfall and damage potential over Chennai using interpolation techniques.

Review of Literature

According to global estimates of 2014 on people displaced by disasters, on an average, 27 million people got displaced each year between 2008 and 2013. In the same time, 80.9 per cent of displacement took place in Asia. The region accounted for the 14 largest displacements of 2013 and the five countries with the highest displacement levels: namely Philippines, China, India, Bangladesh and Vietnam. Since 1970, displacement has increased with regard to both weather-related and geophysical hazards. Displacement due to weather-related hazards has increased more rapidly which corresponds to the development of urban growth in areas exposed to cyclones and floods, particularly in Asia. For any disaster, community involvement has become one of the chief priorities for establishing effective partnerships for disaster risk reduction according to the UNISDR Hyogo Framework for Action (2005-2015) (UNISDR, 2005).

Regarding disasters, identifying risk factors and understanding the way in which communities cope and adapt themselves to hazardous environments are considered important determinants for risk reduction and decision making at local and municipal level. Union Minister for Environment and Forests Prakash Javadekar termed the Chennai floods a "natural disaster of unprecedented scale", and said it provided lessons to improve urban planning and improve city governance - "Chennai gives a lesson, and we must learn from this lesson and improve our urban planning and improve city governance, which is very essential. Unless you allow the drains to flow freely to the sea, water will be clogged and that is what has unfortunately happened." According to Sunita Narain (2015), the Director of the Centre for Science and Environment (CSE), New Delhi, the unprecedented floods in the Chennai metropolitan region were the direct result of unregulated urbanisation. According to her, "our urban sprawls such as Delhi, Kolkata, Mumbai, Chennai, and Srinagar have not paid adequate attention to the natural water bodies that exist in them.

In Chennai, each of its lakes has a natural flood discharge channel which drains the spill over. But we have built over many of these water bodies, blocking the smooth flow of water. We have forgotten the art of drainage. According to research conducted by CSE, Chennai had over 600 lakes in the 1980s, but a master plan published in 2008 showed only a fraction of them survived the human encroachments.

State records show that 19 major lakes shrank from 1,130 hectares in the 1980s to around 645 hectares in the early 2000s, reducing their storage capacity. Drains carrying surplus water from tanks to other wetlands have also been encroached upon, while city storm water drains are clogged and require immediate dredging and desilting. Chennai has only 855 km of storm water drains against 2,847 km of urban roads, resulting in flooding after even a marginally heavy downpour.

Remote sensing (RS) techniques along with Geographic Information System (GIS) have been applied extensively in recent times and are recognized as powerful and effective tools for detecting land-use change, flood mapping and flood risk assessment. (Sarma 1999; Islam and Sado 2000; Sanyal and Lu 2004; Dewan et al 2007). McColl and Aggett (2007) emphasized that the citizens' involvement during the planning process would increase the quality of land use plans, enhance the general sense of community and generate a greater level of trust through increased transparency.

Zhang et al (2008) state that in addition to natural processes, human activities driven by socioeconomic factors should be considered for the increasing level of flood risks. Shang and Wilson (2009) examined the effect of watershed urbanization on stream flow behavior. Stream gauge data, spatially distributed rainfall data, land use/land cover and census population data were used to quantify the change in flood behavior and urbanization in multiple watersheds. They used GIS based methods for quantifying spatially distributed rainfall and surface imperviousness. They concluded that both the frequent and rare floods were sensitive to urbanization and result in increased magnitude of floods with various recurrence intervals.

There is increasing evidence that combination of local knowledge with modern information systems (GIS, GPS, PGIS) and earth observation products (satellite imagery, aerial and oblique photography), can enhance the way in which decisions are made by providing better information (O'Neill, 2003; IFRC, 2005). However, to date, the advantages of participatory collection of risk-related spatial information within a GIS context have not been widely explored. On the positive side, sketches, paper maps, historical profiles and other results obtained through participatory mapping are not kept or updated after a risk assessment project got over, leading to a loss of valuable information.

Cannon et al. (2003) recommend that these products need to be converted from raw data into useful spatial information that allows the community and other actors to develop analytical processes for risk analysis and exploration of risk reduction alternatives. This spatial and non-spatial information integrated in modern geo-information systems can be used to forecast flood hazards, estimate risk much more effectively, and moreover communicate local concerns and capacities to the ‘higher ups’.

Northeast Monsoon 2015

Northeast Monsoon (October to December) season is the crucial period during which Chennai receives up to 30 per cent of its annual rainfall. Unlike the spatially widespread rainfall received during southwest monsoon, rainfall during the northeast monsoon is sporadic. However, over Chennai, the rainfall during northeast monsoon by far exceeds the amount produced by southwest monsoon by up to 90 per cent. Normally, coastal districts of Andhra Pradesh usually bear the brunt of heavy rains that occur during the northeast monsoon; with numerous river systems and wetlands, Pondicherry and eastern Tamil Nadu are prone to flooding.

Chennai city alone experienced five major floods between 1943 and 2005, with the 1943, 1978, 1985 and 2005 floods causing particularly severe damage. Furthermore, unplanned and often illegal urban development has led to many wetlands and natural sinks being built over; this, along with ageing civic infrastructure and poorly designed drainage systems, has resulted in an increased frequency of severe flooding as was observed in 2015. On 8 November 2015, a low pressure area developed into a depression and slowly intensified into a deep depression before crossing the coast of Tamil Nadu near Pondicherry the following day. Because of land interaction and high vertical wind shear, the system weakened into a well-marked low pressure area over north Tamil Nadu on 10 November. The system brought very heavy rainfall over the coastal and the north interior districts of Tamil Nadu. On 15 November, another well-marked low pressure area moved northwards along the Tamil Nadu coast, pouring in heavy rainfall over the coastal Tamil Nadu and Andhra Pradesh with 24 hour totals peaking at 370 mm in Ponneri (near Chennai). Chennai International Airport recorded 266 mm of rainfall in 24 hours. On 28–29 November, yet another system developed and ready to hit Tamil Nadu on 30 November, bringing exceptionally heavy rainfall and subsequent flooding. The system dropped 490 mm of rainfall at Tambaram (southern suburb of Chennai) in 24 hours starting 8:30 am on 1 December. Very heavy rains led to flooding across the entire stretch of the coast from Chennai to Cuddalore.

Incessant rains led to low-lying areas of Chennai becoming inundated. The flooding in Chennai city had worsened over the years by unplanned and illegal urban development, in particular around the southern fringes and inadequate knowledge on flood preparedness. Much of the city remained flooded on 17 November and 1-2 December (Refer photo showing the flooded localities in Chennai), though rainfall had largely showed a declining trend by then after 3 December. Chennai received 1,049 mm of rainfall in November 2015, the highest recorded since November 1918 when 1,088 mm of rainfall was recorded. The flooding in Chennai city was described as the worst in a century. The continued rains led to schools and colleges remaining closed across Pondicherry and Chennai, Kancheepuram and Tiruvallur districts in Tamil Nadu and fishermen were warned against sailing because of high waters and rough seas.

Figure 1: Flooded huts in Chennai in December 2015

Adyar River – Reason for Flooding

A special note is essential to mention about the Adyar River as in the recent floods of Chennai. It left many residents wondering about the flooding in areas that were usually not inundated in the past. The reason is that the Chembarambakkam reservoir, which chiefly contributed to floods in Adyar River, received the highest inflow in 100 years on December 1 2015, much more than the capacity fixed based on flood data of 60 years. The reservoir's capacity was improved in 1996 to handle an inflow of 33,400 cubic feet per second (cusecs). This equals to nearly 10 lakh litres per second. Reliable sources say that the reservoir received was more than 35,000 cusecs on the midnight of December 1. "If 35,000 cusecs were released into the river, it would have only taken three hours for the flood. But, the discharge was moderated to 29,400 cusecs that took six to nine hours for the flood water to flow into the river. We could not have discharged lesser volume of water as the inflow was beyond the reservoir's capacity to handle," said the official source. Discharge is moderated according to the inflow and the rainfall over the water body. Normally, the reservoir's levels are maintained two feet lower than the maximum level during the rainy season. This is to accommodate stepping up storage when the inflow is less. Former officials recalled that the reservoir was improved to discharge 21,000 cusecs in 1980s and later to 33,400 cusecs. Even weirs, structures that allow surplus water to flow automatically were converted into regulators to moderate huge inflow of over 33,400 cusecs in 1996.

The below figure depicts the inflow-outflow of the Chembarambakkam Lake between 10 November and 5 December 2015. This was the time when the reservoir received its record rainfall as inflow and discharge as outflow as flood. This huge volume of water discharge has resulted in the flooding of major portions of the southern Chennai and its environs.

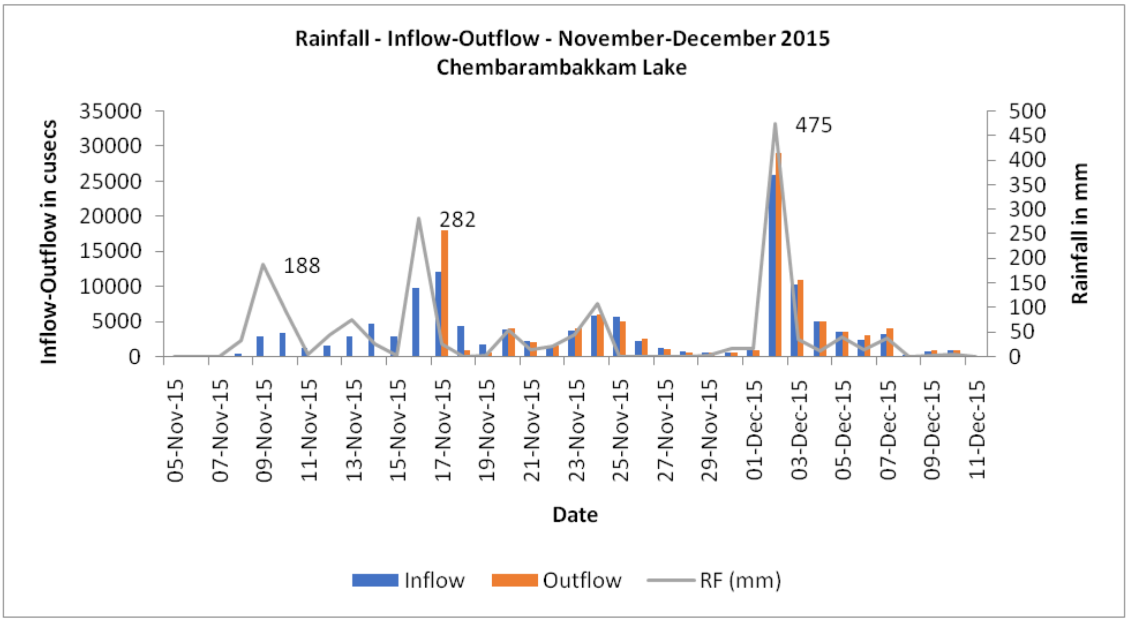

Figure 2: Rainfall – Inflow - outflow (November-December 2015), Chembarambakkam Lake

Rainfall distribution

Rainfall is an important variable that determines the nature of climate of a region. Rainfall which is so variable in space and time is highly disconnected over a given geographical area. In spite of having the best historic rainfall data of rain gauge stations, the representation is point based (rain gauge station) and not continuous. This discrete nature of rainfall data contributes to the challenges in interpolation where rainfall is highly variable. Inverse Distance Weighting (IDW) is one of the most successful techniques in understanding the rainfall variability in a given space and has been used to map the rainfall distribution on 2 December 2015.

There are several studies which have been conducted using IDW method to assess the rainfall distribution (Feng-Wen Chen, 2012). Azpurua M (2010) concluded that IDW interpolation method is most likely to produce the best estimation of a continuous surface of the average magnitude of electric field intensity.

S.No.	Rainfall stations	Rainfall (mm)
1	Tambaram	494
2	Chembarambakkam	475
3	Minambakkam	340
4	Poonamallee	336
5	Red hills	320
6	Anna University	319
7	Kolapakkam	310
8	Taramani	300
9	Nungambakkam	294

Table 1: Rainfall on 2 December 2015 over Chennai

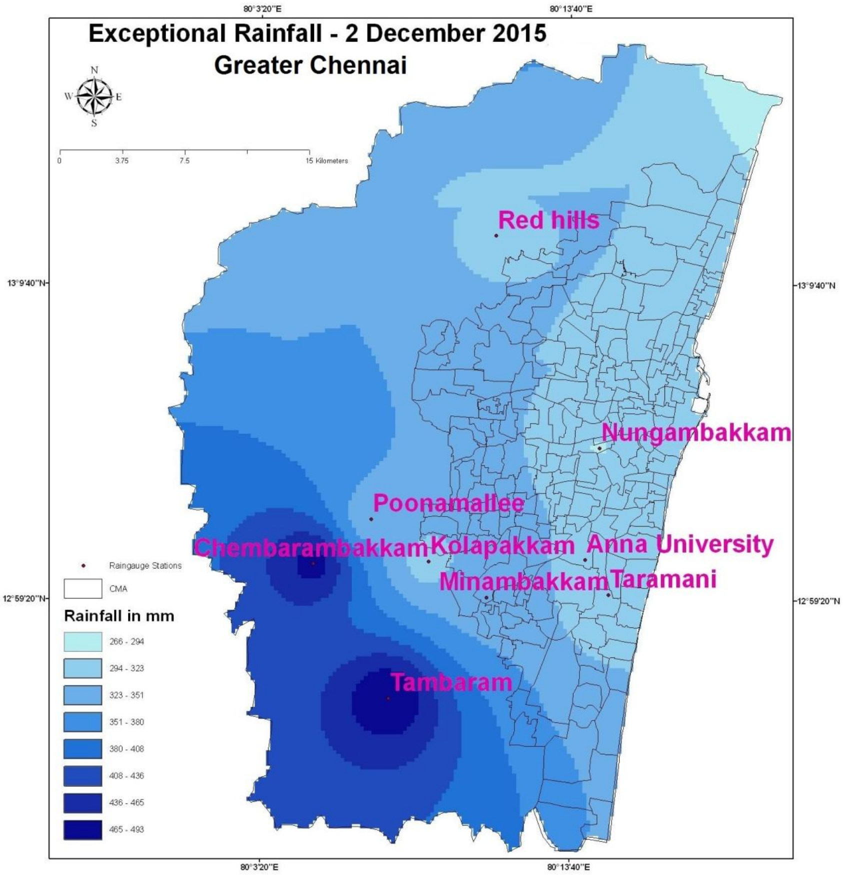

Figure 3: Rainfall distribution on 2 December 2015 – Chennai city

For the stations mentioned in the Table 1, rainfall was plotted as point data using its latitude and longitude. Then interpolation technique in ArcGIS was used to produce the continuous rainfall distribution over Chennai Metropolitan Area (CMA). CMA boundary was used to set the extent of the Chennai rainfall distribution pattern. It was evident from the rainfall distribution map that the southern region, especially adjoining Chembarambakkam and Tambaram had exceptional rainfall. Actually, the Chembarambakkam rainfall station is located within the Chembarambakkam Lake area and is a clear indication of the volume of rainfall recorded.

Future course of action

Monsoon rainfall in 2015 was exceptionally heavy and resulted in extensive flooding, in particular the southern Chennai after the record volume of water release from Chembarambakkam reservoir on 1-2 December 2015. Published rainfall data covering Chennai Metropolitan Area was populated with its rainfall and plotted its distribution across Chennai geography using interpolation technique. This technique is useful in understanding the extent of rainfall and its spread. The accuracy of this distribution improves when more rain gauge stations data is available within the area of interest.

As part of the recommendations, the following are suggested:

(a) Removal of encroachments and this has already been initiated on a war footing along the lakes and rivers passing through Chennai Metropolitan Area.

(b) Like a coastal regulation zone which extends up to 500 m high tidal line, a buffer zone of 100-200 m should be identified on both the river banks to protect it as green zone and to ensure limited human infrastructure.

(c) Development of parks and greeneries along the river banks help to check the soil erosion and strengthen the bank.

(d) Flood plain zoning, which places restrictions on the use of land on flood plains, can reduce the cost of flood damage. This involves comprehensive urban land use management with year on year updates to monitor the emergence of illegal construction.

(e) An effective Early Warning System is one that can issue warning in advance, i.e. 72 hrs, 48 hrs. and 24 hrs. or on hourly basis (nowcast) during periods of landfall of cyclone. It can change the existing scenario substantially and facilitate informed decision making in embracing proper measures towards disaster preparedness, mitigation, control, planning and management. This kind of advance warning can help the authorities for better flood preparedness and also effective flood mitigation.

(f) Displaying the flood vulnerability maps at prominent locations (vulnerable locations) would improve the knowledge level of the populace. As a support to this, free digital maps of each vulnerable communities/localities could be made available to the community leaders to prepare their neighbourhood.

(g) Spatial Vulnerability - For each river basin and its sub-basin, a geospatial database should be created. It would be possible to delineate the physical vulnerability of the basin to flood after geographical analysis. If the river basin or sub-basin is located within or close to the city limit, then it needs a regular preparation (1-2 years period) of the vulnerability.

(h) Social Vulnerability – After all, it is the community who face the brunt of the natural calamity. It is very essential to know the vulnerable population ahead of natural disasters and knowing their spatial distribution helps to reach them early and safeguard before it is too late. Gather demographic data at the smallest possible administrative level on vulnerable population like children, women, aged, physically challenged, unemployed and unschooled population. All form the socially vulnerable group where it is essential to know their distribution across the space and take necessary steps to rehabilitate them to safer locations in advance.

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