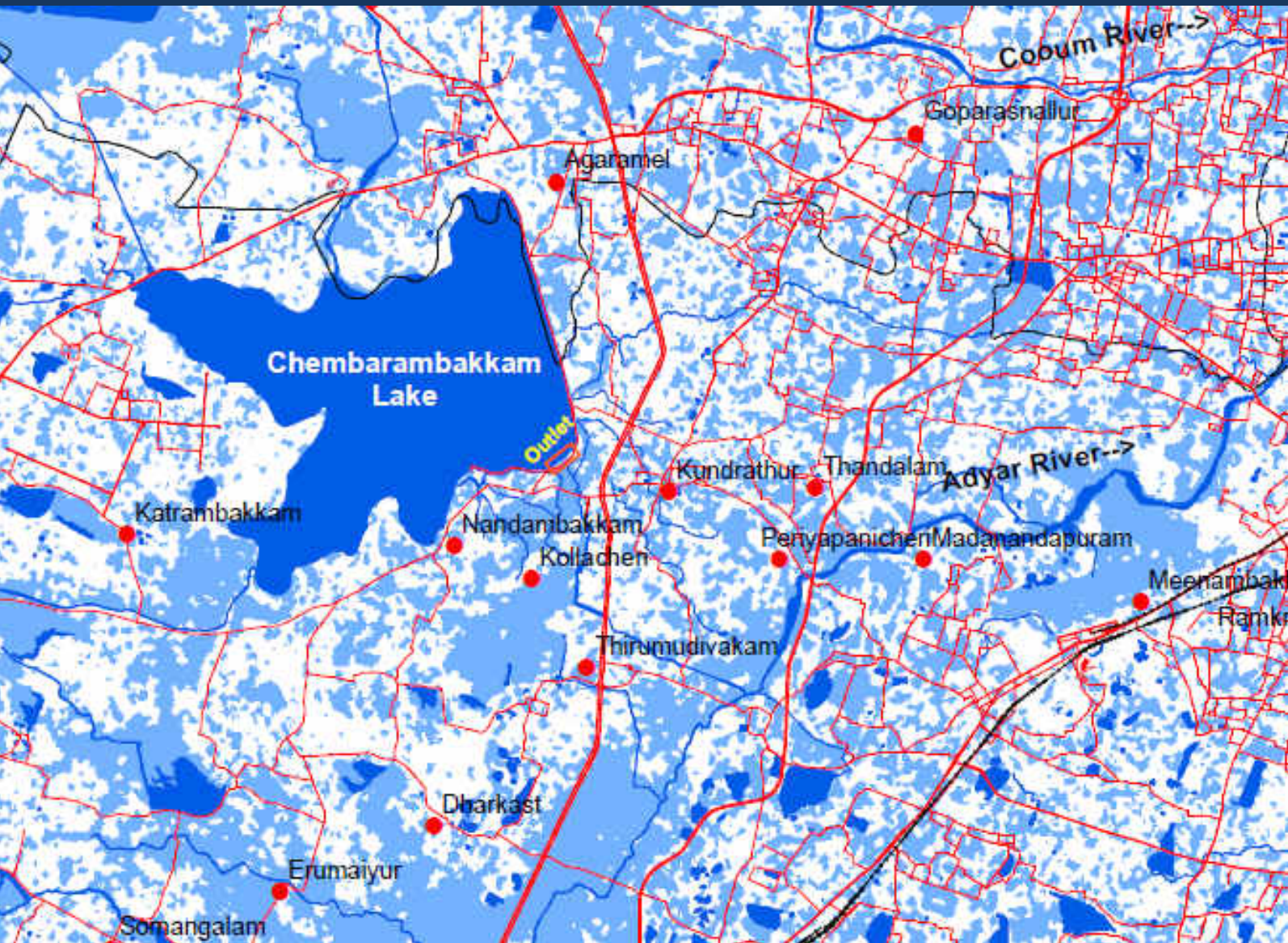


Chennai Floods, 2015

[A Satellite and Field Based Assessment Study]



Disaster Management Support (DMS) Division
National Remote Sensing Centre
(NRSC / ISRO)
Hyderabad, India



Chennai Floods, 2015
[A Satellite and Field Based Assessment Study]

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NATIONAL REMOTE SENSING CENTRE

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Executive Summary

South India experienced heavy rains during the month of November and December, 2015 due to the formation of depression over southwest Bay of Bengal and owing to a strong El Niño. Heavy widespread incessant rainfall activity led to waterlogging and flood like condition in parts of Karnataka, coastal Andhra Pradesh and Tamil Nadu. Tamil Nadu was one of the worst affected states and Chennai in particular was one of the worst hit districts.

Decision Support Centre (DSC) at National Remote Sensing Centre (NRSC), ISRO, kept a close watch on the flood situation since November, 2015. Emergency requests for tilting the IRS cameras and tasking of Indian Microwave Satellite RISAT-1 and activating of International Charter was done to acquire multi-sensor and multi-date satellite datasets over the affected region. Rapid inundation mapping and monitoring was carried out and the inundation products were disseminated in near real time. About 26 inundation maps state, district and detailed inundation maps, cumulative maps, progression and recession maps were sent to MHA, NDMA, and Govt. of Tamil nadu to help in relief and rescue operations. Special efforts were put to map the inundation within the Chennai city and prepare maps highlighting the settlements affected along Adiyar and Cooum Rivers.

The inundation products and layers were continuously published on Bhuvan and NDEM (National Database for Emergency Management) web portals. Value added satellite images showing the status of the flood situation in parts of Chennai district were also published on NRSC website. An Android based mobile application was developed by Bhuvan Team to facilitate crowd sourcing. A field survey in collaboration with Indian Institute of Technology (IIT), Chennai was carried out during 24-26 December, 2015 to have a closer assessment of the catastrophic flood and collect information on flood water depth marks.

This report describes about the flood event, satellite mapping and monitoring of floods and field assessment of the inundated areas carried out for Chennai floods of December, 2015.

Chennai Floods, 2015

1.0 Introduction

South India experienced heavy rains during the month of November and December, 2015 due to the formation of depression over southwest Bay of Bengal and owing to a strong El Niño. Heavy widespread incessant rainfall activity led to waterlogging and flood like condition in parts of Karnataka, coastal Andhra Pradesh and Tamil Nadu. Tamil Nadu was one of the worst affected states where rainfall in all but two of the 34 districts in the state has exceeded the normally observed levels, while five districts have been pounded by over twice the average rainfall received between October and the end of November, 2015 (Fig-1). Chennai in particular was one of the worst hit districts in the state which received almost 1,200 mm of rain in November, which is nearly 300 per cent above the normal observation of 407.4 mm. While rainfall in the city broke the nearly century-old record for November, the record for the highest rainfall received in a single day in December was also rewritten. On December 1–2, 2015, the Indian city of Chennai received more rainfall in 24 hours than it had seen on any day since 1901. The previous record for rainfall in a single day in December dates back to 1901 when the city received 261.6 mm of rainfall in a span of 24 hours. On December 1, 2015, the city received around 290 mm of rain in a single day causing catastrophic flood disaster. The deluge followed a month of persistent monsoon rains that were already well above normal for the Indian state of Tamil Nadu.

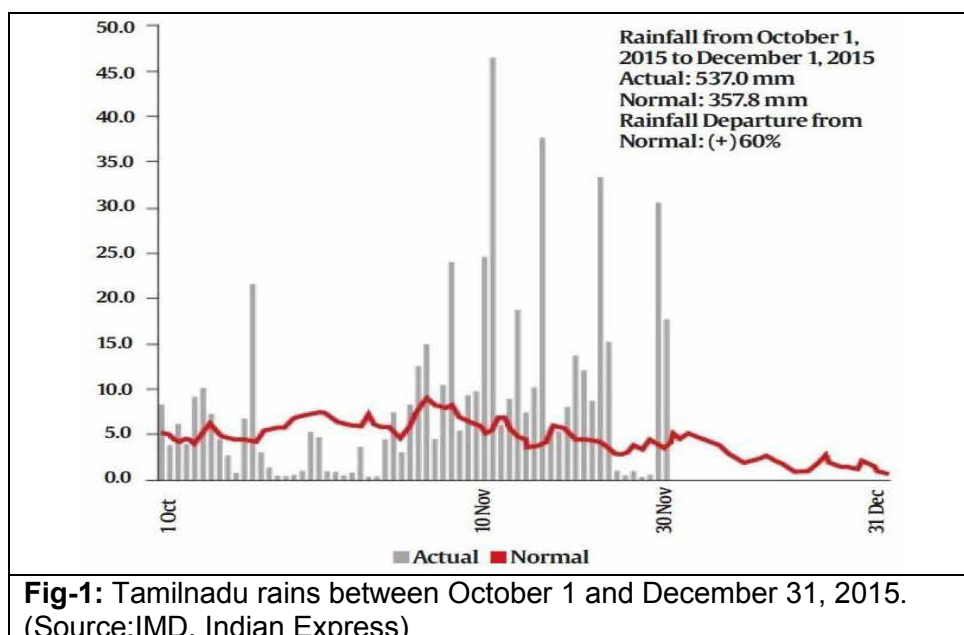


Fig-1: Tamilnadu rains between October 1 and December 31, 2015. (Source:IMD, Indian Express)

From Fig-2 which shows distribution of seasonal rainfall between October 1, 2015 and December 9, 2015 from IMD Regional Meteorological Centre Chennai, it can be observed that in 9 districts viz. Ariyalur, Chennai, Cuddalore, Puducherry, Kancheepuram, Tirunveli, Tiruvallur, Vellore and Villupuram of Tamilnadu percentage departure from normal was more than 100.

GOVERNMENT OF INDIA, MINISTRY OF EARTH SCIENCES							
INDIA METEOROLOGICAL DEPARTMENT							
REGIONAL METEOROLOGICAL CENTRE, CHENNAI							
Districtwise daily / seasonal rainfall distribution for Tamil Nadu & Puducherry of date 09.12.2015							
NEM 2015 RAINFALL		09.12.2015**			From 01.10.2015 to 09.12.2015		
CODE	NAME	ACTUAL in mm	NORMAL in mm	PDN*	ACTUAL in mm	NORMAL in mm	PDN*
	STATES						
32	PUDUCHERRY (UT)	17.1	9.8	74	1460.2	772.8	89
31	TAMIL NADU	7.6	4.3	77	646.3	392.9	64
	MET. SUBDIVISIONS						
31	TAMIL NADU & PUDUCHERRY						
534	ARIYALUR	5.4	8.1	-34	669.4	470.6	42
461	CHENNAI	6.9	10.2	-32	1612.1	708.6	128
462	COIMBATORE	0.5	3.7	-86	331.7	305.1	9
463	CUDDALORE	8.8	7.5	18	1215.6	603.2	102
464	DHARMAPURI	3.6	4.1	-13	445.0	308.5	44
465	DINDIGUL	3.9	3.4	16	467.3	384.0	22
466	ERODE	0.6	3.2	-82	391.9	293.7	33
467	KANCHEEPURAM	10.7	9.8	9	1808.6	577.5	213
468	KANYAKUMARI	20.5	3.1	563	712.1	461.8	54
636	KARAIKAL	35.4	16.8	111	1291.8	855.1	51
469	KARUR	2.4	3.1	-24	358.2	288.7	24
470	KRISHNAGIRI	0.8	3.0	-73	441.0	272.2	62
471	MADURAI	1.1	2.1	-50	395.7	381.2	4
472	NAGAPATTINAM	62.1	12.1	413	1339.0	786.5	70
473	NAMAKKAL	0.8	2.1	-60	308.3	275.6	12
474	NILGIRIS	8.6	3.4	153	550.5	436.6	26
475	PERAMBALUR	0.9	7.1	-87	524.1	391.0	34
476	PUDUCHERRY	7.1	6.0	18	1552.1	727.8	113
477	PUDUKOTTAI	31.2	3.2	876	551.1	352.0	57
478	RAMANATHAPURAM	9.5	2.5	278	495.8	422.1	17
479	SALEM	1.1	5.7	-81	481.1	344.3	40
480	SIVAGANGA	9.2	1.8	413	420.2	369.7	14
481	THANJAVUR	30.1	6.5	364	664.8	474.7	40
482	THENI	0.4	2.1	-81	382.7	327.0	17
483	TIRUNELVELI	19.5	3.2	510	907.0	403.1	125
535	TIRUPPUR	0.6	1.4	-58	344.3	290.2	19
484	TIRUVALLUR	1.1	5.7	-81	1468.5	532.3	176
485	TIRUVANNAMALAI	0.8	4.9	-85	589.5	406.4	45
486	TIRUVARUR	32.0	8.8	263	939.3	606.5	55
488	TOOTHUKUDI	6.2	1.6	289	544.7	373.7	46
487	TIRUCHIRAPALLI	7.4	4.0	86	438.8	350.6	25
489	VELLORE	0.0	4.8	-99	745.3	319.4	133
490	VILLUPURAM	1.0	6.1	-84	920.2	436.8	111
491	VIRUDHUNAGAR	0.7	2.5	-72	454.6	379.3	20
	SUBDIVISION RAINFALL	7.6	4.3	77	649.1	394.2	65
LEGEND	PDN*	Percentage Departure from Normal					
	**	Rainfall for the 24 hrs ending at 0830 hrs of date					

Fig-2: District-wise seasonal rainfall for Tamilnadu between October 1 and December 9, 2015. (Source:IMD)

Floods were so severe that the entire city was brought to stand still for many days. Chennai international airport was also inundated under water and all the flights and airport operations were halted upto December 6, 2015. Economic losses to the tune of \$7 billion, more than 400 people losing their lives and 18 lakh being displaced due to this event was reported (Source:Wikipedia). In an interview published in Navbharat Times, Director General, National Disaster Response Force (NDRF) termed it as one of the biggest flood rescue operations carried out by NDRF. Flooding problem was more aggravated because Chennai is one of the largest industrial commercial center in South India and in recent decades has experienced large-scale population growth in Chennai and its suburbs (Krishnamurthy et.al., 2015). Chennai floods of December, 2015 are a classic example of urban flooding and the unprecedented flood situation witnessed by the city has again reignited the problem of urban flooding not only in India but globally. The catastrophic flooding event also attracted the attentions of experts assembled at Paris during the COP-21 to discuss climate change.

2.0 Chennai

Chennai, the capital city of Tamil Nadu, is located in the North-Eastern corner of Tamilnadu. The Chennai Metropolitan Area (CMA) comprises the city of Chennai, 16 municipalities, 20 town panchayats (local governing bodies) and 214 village panchayats. The extent of CMA is 1189 km². The CMA falls in three districts of the Tamil Nadu state i.e. Chennai district (area: 176 km²), and parts of Thiruvallur district (area: 637 km²) and Kancheepuram district (area: 376 km²).

2.1 Population

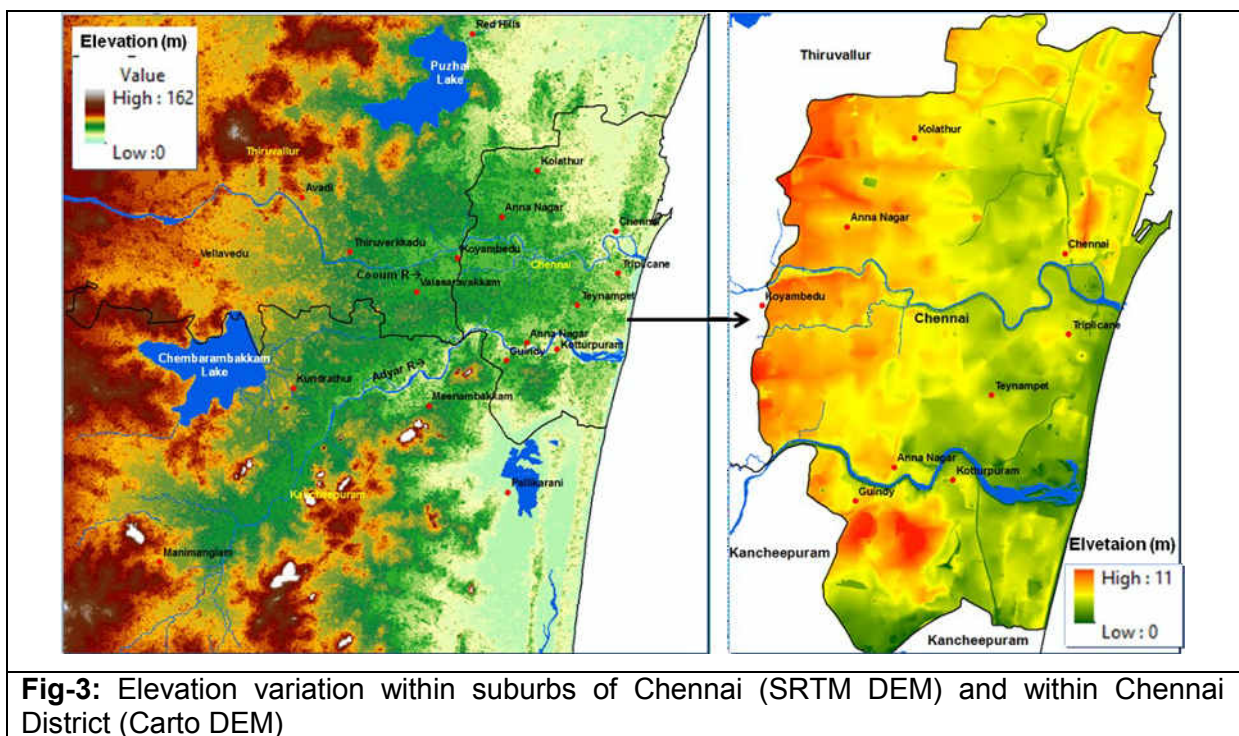
As per data released by Govt. of India for Census 2011, Chennai is an Urban Agglomeration coming under category of Million Plus UA/City. Its total population is about 8,653,521 and is one of the largest cities of South India (<http://www.census2011.co.in/census/metropolitan/>). Chennai has witnessed a tremendous growth in its manufacturing, retail, health care and IT sector in the last 10 years. It is regarded as India's fourth largest city after Delhi, Mumbai and Kolkata. Being a major business hub of the state, the population of Chennai has witnessed a rapid growth in its Population.

2.2 Drainage

The City is drained by 2 rivers the Adyar and the Cooum Rivers, besides a number of major and minor drains through Buckingham Canal into Sea via Ennore Creek and Kovalam Creek. Cooum runs through the heart of the city whereas Adyar wends its way through the southern part of the city before entering into the sea. Though the river Adyar can be traced to a point near Guduvancheri village, it assumes the appearance of a stream only after it receives the surplus water from the Chembarambakkam tank as wells as the drainage of the areas in the south-west of Chennai. Cooum River starts from Kesavaram Anicut in Kesavaram village built across Kortaliyar River. The surplus from Cooum tank joins this course at about 8 kms. lower down and this point is actually the head of Cooum River which is located at 48 kms. west of Chennai.

2.3 Physiography

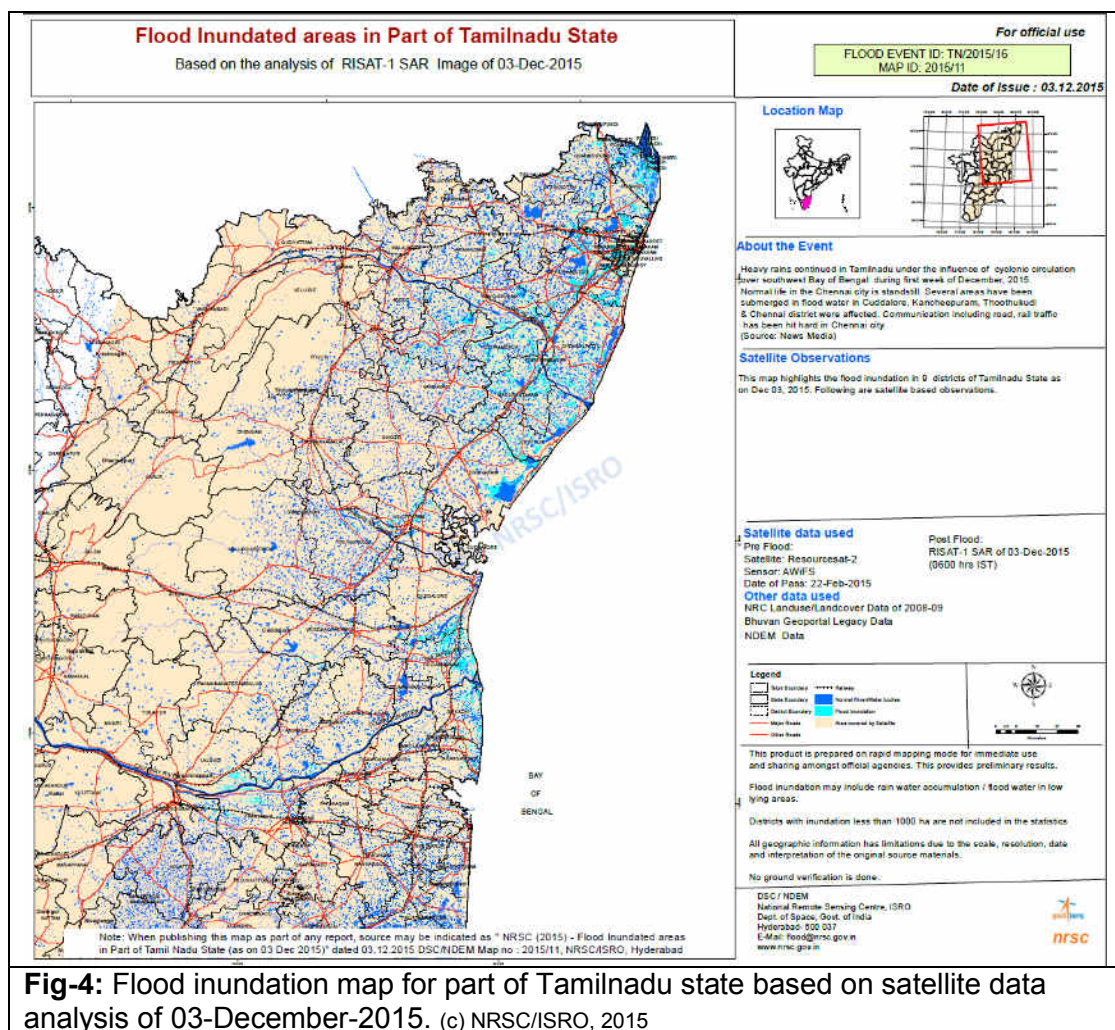
Chennai is a low-lying area and the land surface is almost flat like a pancake. The elevation variation within Chennai district varies between 0 to 11m, with mean elevation being about 6m (Fig-3). The even topography of the land throughout the district renders sub-divisions into natural regions rather difficult. Most of the localities are just at sea-level and drainage in such areas remains a serious problem. Chennai City has experienced major flooding during 1943, 1976, 1985, 1996 and 2005



3.0 Efforts of DSC

3.1 Tamilnadu Flood Mapping and Monitoring

At NRSC/ISRO, Decision Support Centre (DSC) kept a close watch on the flood situation due to heavy incessant rains in Tamil nadu since November, 2015. Rapid inundation mapping and monitoring was carried out and the inundation products were disseminated in near real time to MHA, NDMA, and Govt. of Tamil nadu to help in relief and rescue operations. About 26 inundation maps state, district and detailed inundation maps, cumulative maps, progression and recession maps were sent. Fig-4 shows flood inundation map for part of Tamilnadu state based on satellite data analysis of 03-December-2015.



3.2 Chennai Inundation Mapping and Monitoring

RISAT-1 satellite data of 03, 04 & 06-December-2015 was acquired and analyzed to generate a cumulative inundation layer. Maps showing inundation in areas adjoining Chembarambakkam Lake and Chennai district were prepared (Fig-5 and Fig-6).

Cumulative inundation layer was integrated with base information like roads, rail, settlements to generate detailed inundation maps showing the settlements and stretches of road and rail submerged were prepared for areas affected around Adiyar River and Cooum River and provided to the district agencies (Fig-7 and Fig-8).

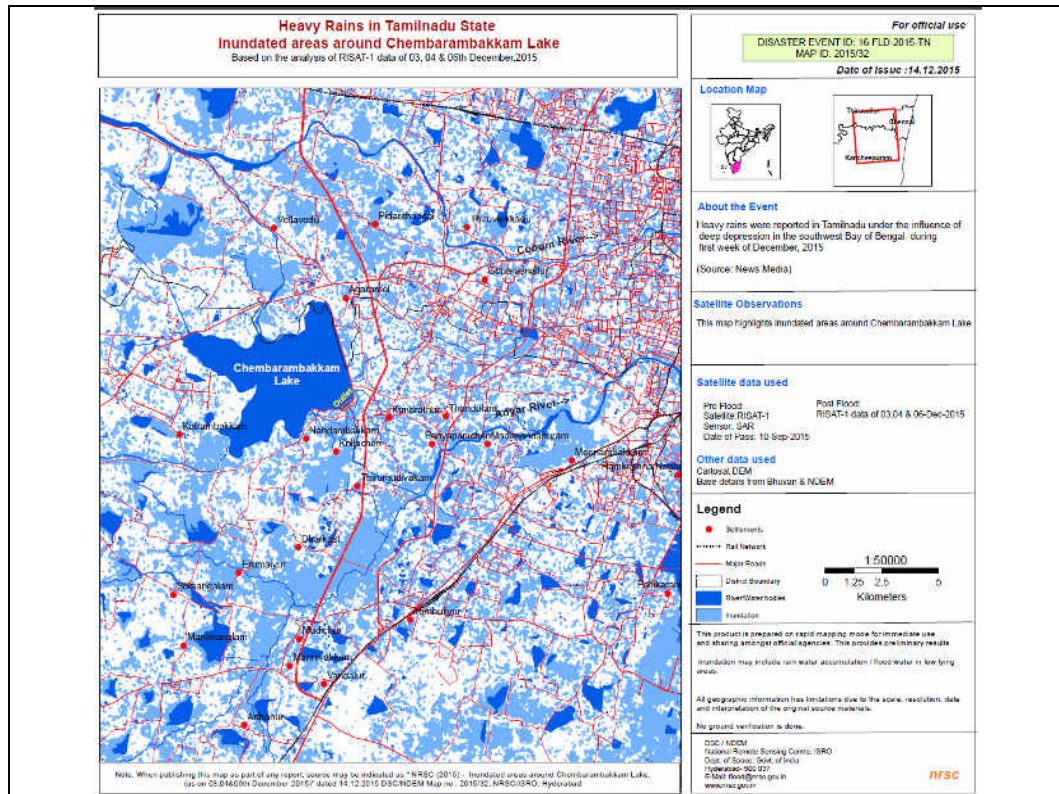


Fig-5: Inundated areas around Chembarambakkam Lake. (c) NRSC/ISRO, 2015

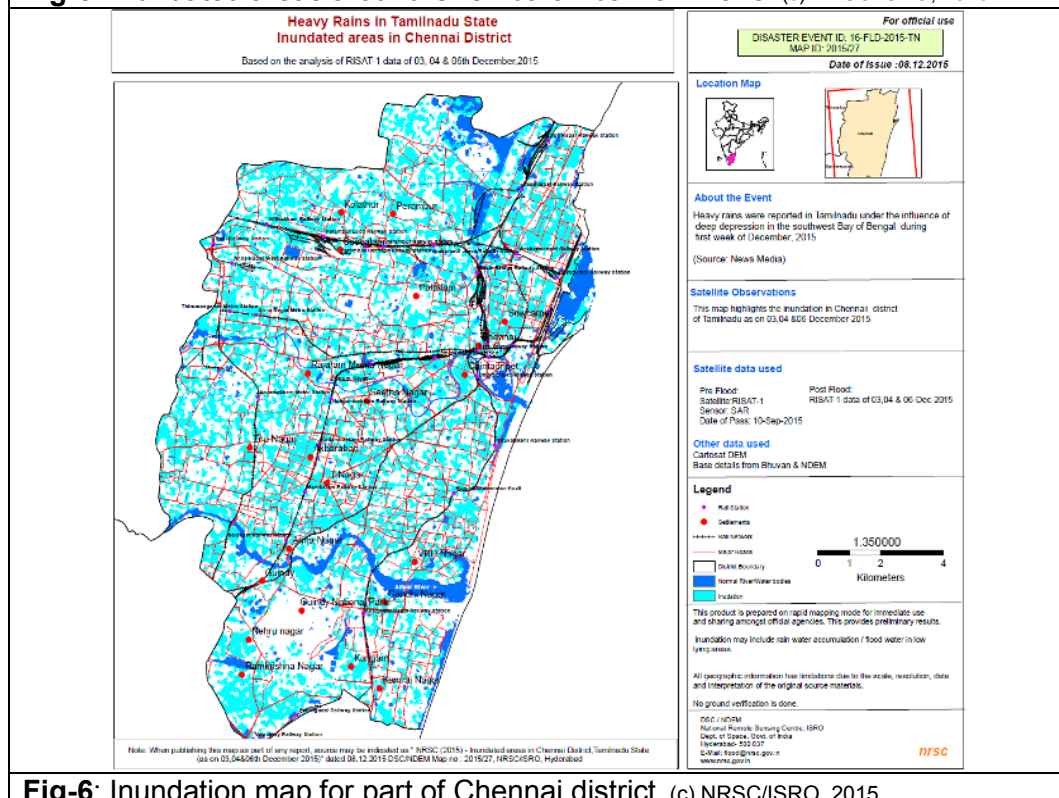


Fig-6: Inundation map for part of Chennai district. (c) NRSC/ISRO, 2015

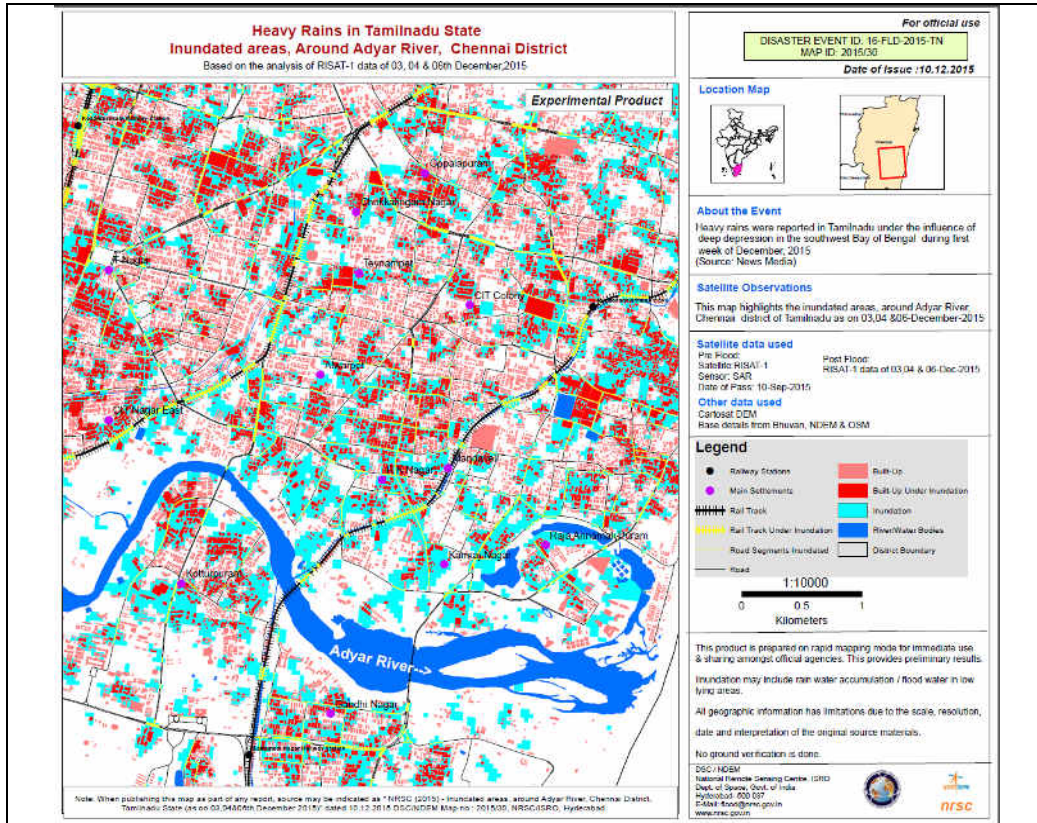


Fig-7: Detailed map showing inundated areas around Adyar River based on satellite data analysis of 03, 04 & 06-December-2015. (c) NRSC/ISRO, 2015

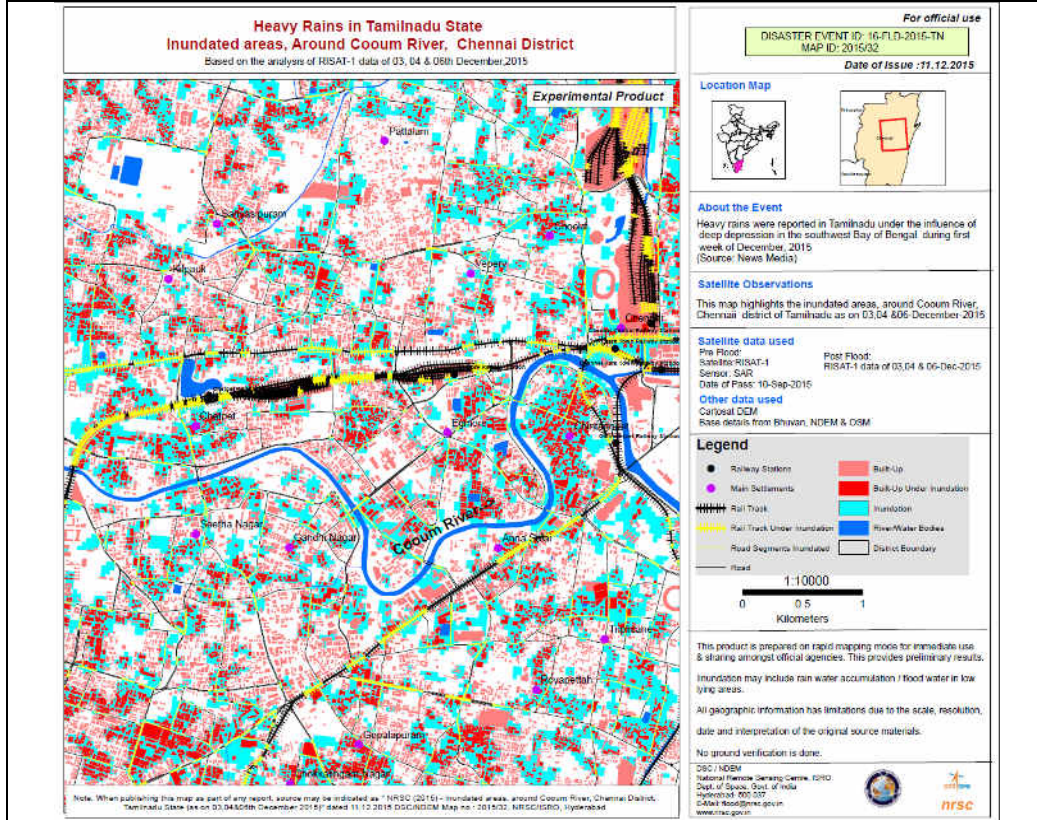
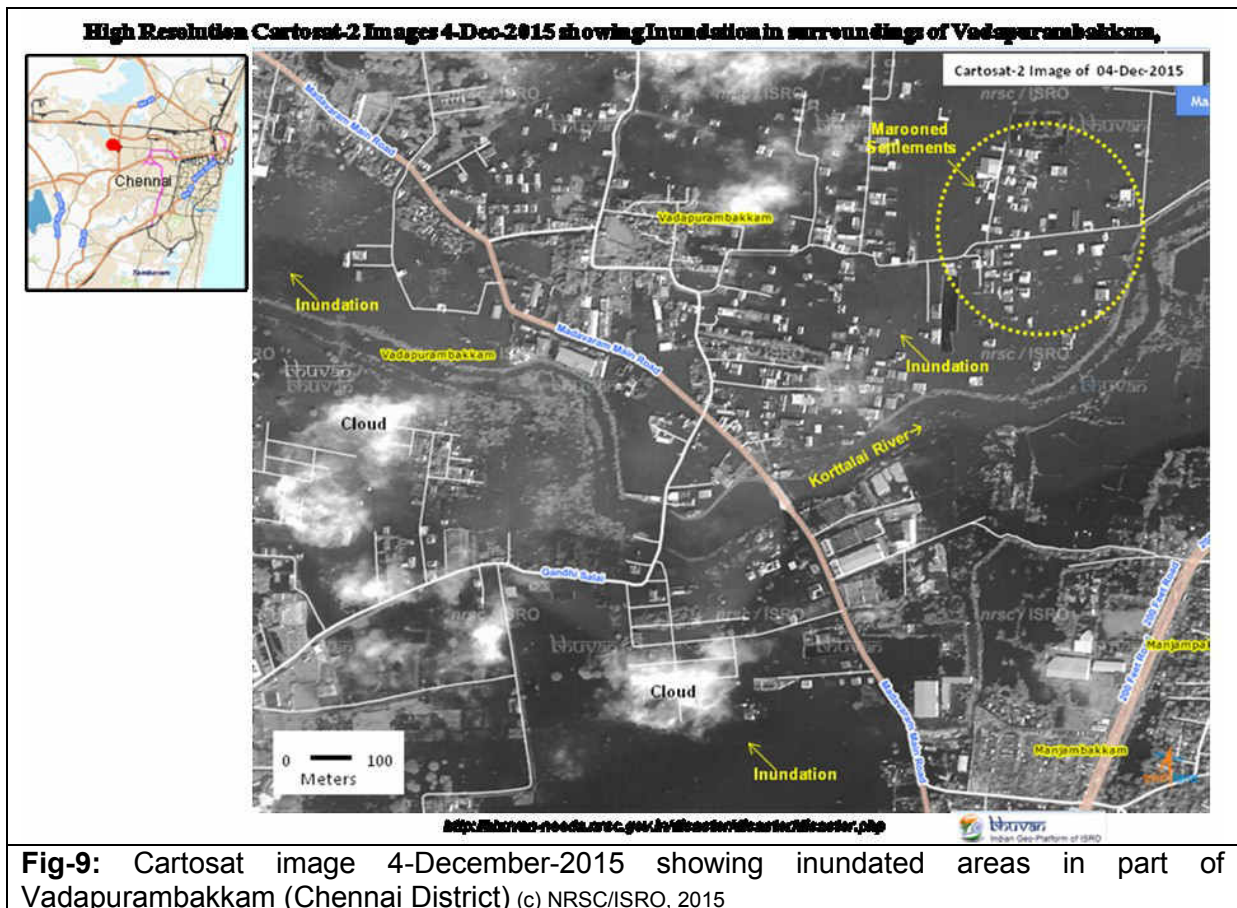


Fig-8: Detailed map showing inundated areas around Cooum River based on satellite data analysis of 03, 04 & 06-December-2015. (c) NRSC/ISRO, 2015

The inundation products and layers were continuously published on ISRO's geovisualization portal "Bhuvan" (www.bhuvan.nrsc.gov.in) and NDEM (National Database for Emergency Management) web portals. Value added satellite images showing the status of the flood situation in parts of Chennai district were also published on NRSC website (www.nrsc.gov.in) (Fig-9). An Android based mobile application was developed by Bhuvan Team to facilitate crowd sourcing.



4.0 Field Survey

NRSC, DMSD team in collaboration with Indian Institute of Technology (IIT), Madras, Chennai carried out a field investigation during 24-26 December, 2015 to have a closer assessment of the catastrophic floods, validate the satellite based inundation layer and collect information on flood water depth marks. During this field survey 14 Chennai municipal corporation zones (Manali, Royapuram, Anna Nagar, Teynampet, Alandur, Adyar, Ambattur, Tondiarpet, Kodambakkam, Perungudi, Sholinganallur, Valasaravakkam, Madhavaram and Thiru. Vi. Ka. Nagar) and also regions adjoining to Chennai district falling in Kancheepuram and Thiruvallur districts were surveyed. During field survey about 55 locations affected by flooding were visited and

information on the inundated locations viz. flood depth, damage and photo of the affected location were collected using an Android based mobile application developed by Bhuvan Team (Fig-10 and Annexure-1). Field data collected using Bhuvan App was subsequently uploaded onto Bhuvan Portal (<http://bhuvan-noeda.nrsc.gov.in/disaster/disaster/disaster.php>).

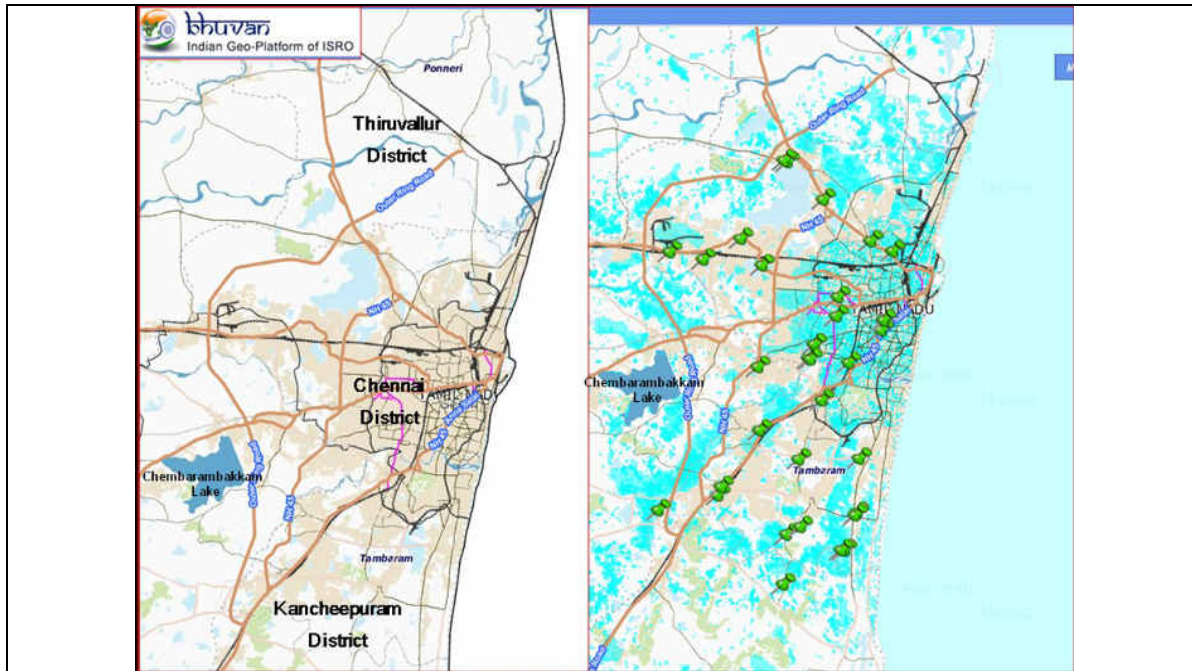


Fig-10: Maps showing spatial locations of the 55 points (green pins) visited during field.

Location 1: Sikkarayapuram (Kancheepuram district)

Chembarambakkam Lake is located near Chennai in Kancheepuram district of Tamil Nadu, India, about 40 km from Chennai. It is one of the two rain-fed reservoirs from where water is drawn for supply to Chennai City, the other one being the Puzhal Lake. The Adyar River originates from a tank near Manimangalam village in Sriperumbadur in Kancheepuram district, but it is only when the water from the Chembarambakkam Lake joins the river that the stream appears. The river then flows through Tiruvallur and Chennai and flows into the Bay of Bengal at Adyar in Chennai. In the intervening night of 1st and 2nd December 2015, during incessant rains, when the PWD Department had to open the flood gates of Chembarambakkam Lake, causing overflowing of river and flooding of residential areas and other parts of Chennai especially adjoining the river. Field inspection of Sikkarayapuram (Chennai district) area near Madha Engineering College which is located downstream of Chembarambakkam lake shows how severe the flood situation would have been in that region. The high velocity and the height of water

which would have passed through the area could be well imagined from the damages caused to the electricity poles, hoardings along roadside and road connectivity in that area (Fig-11). A closer look at the electric poles shows the mud marks indicates that the flood water at this location reached about 20 feet high on December 2, 2015 (Fig-12).



Fig-11: Flood damage to road and electric poles suffered due to gushing flood water at Sikkarayapuram (Kancheepuram district), near Madha Engineering College. (c) NRSC/ISRO, 2015



Fig-12 Layers of dried mud marks clinging to electric pole indicating height water attained on December 2, 2015 at Sikkarayapuram (Kancheepuram district) near, near Madha Engineering College. (c) NRSC/ISRO, 2015

Location 2: Manapakkam (Chennai district)

Manapakkam area is located 0.65km north of Adyar River and is one of the worse affected locations. During field inspection of the Sri Ram Chandra Mission (SRCM) world headquarters located in Manapakkam it was observed that the flood water depth in this area was about 11.5 feet. The website of SRCM mentions about occurrence of unparalled damage to the centre due to the flood waters (<https://www.sahajmarg.org/chennai-floods>). The centre staff told that water had entered the centre in the night of December 1, 2015 and the area was under water for almost 10 days and the water had to be drained out using pumps. The water marks left on the wall and pillars were clear enough to tell that everything would have submerged under 11.5 feet of water and on pillars the high water marks and marks left with recession were very much visible (Fig-13). Severe damage to books, kitchen, and meditation hall and furniture items was visible on inspection of the area.



Location 3: Ashok Nagar (Chennai district)

Ashok Nagar is a densely populated residential locality situated at the southern part of Chennai. It is located about 2 km north of Adyar River. Here the water depth was observed to be at 4.5 feet. Flood water marks outside the house on the window glasses, boundary walls and inside houses from the moisture content on the walls could be well visualized (Fig-14). The mud brought by water and clinging on to the window glasses and walls made a clear demarcation of the depth the flood water attained. Many cars drying outside in the sun was also a very common sight in this locality. The mud markings on the cars glasses at different levels as water receded could be clearly seen and inside the car fungus on the cars dashboard and mud filled inside can be seen (Fig-15). This area was under water for three days and thereafter the water slowly started receding.

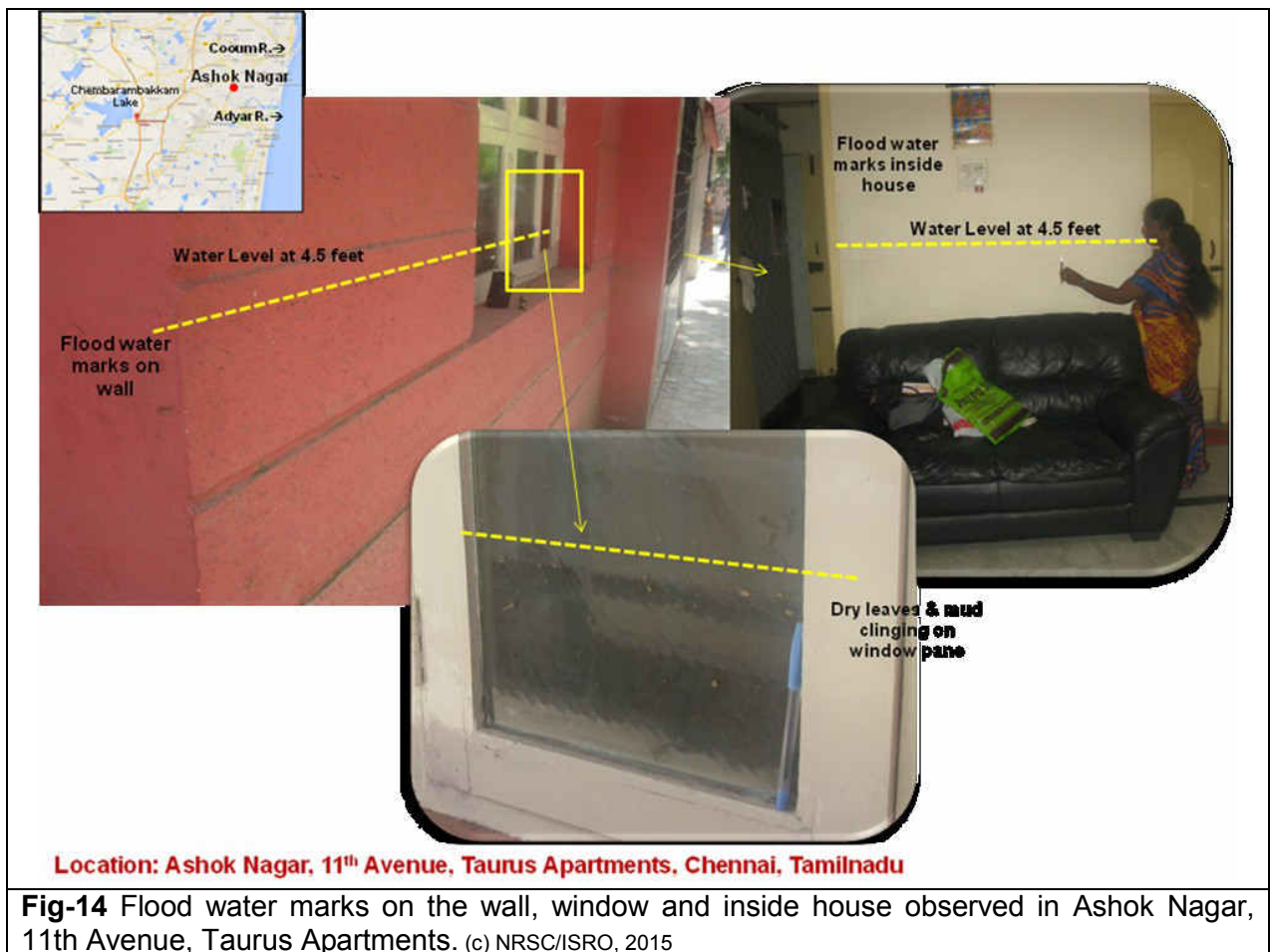


Fig-14 Flood water marks on the wall, window and inside house observed in Ashok Nagar, 11th Avenue, Taurus Apartments. (c) NRSC/ISRO, 2015

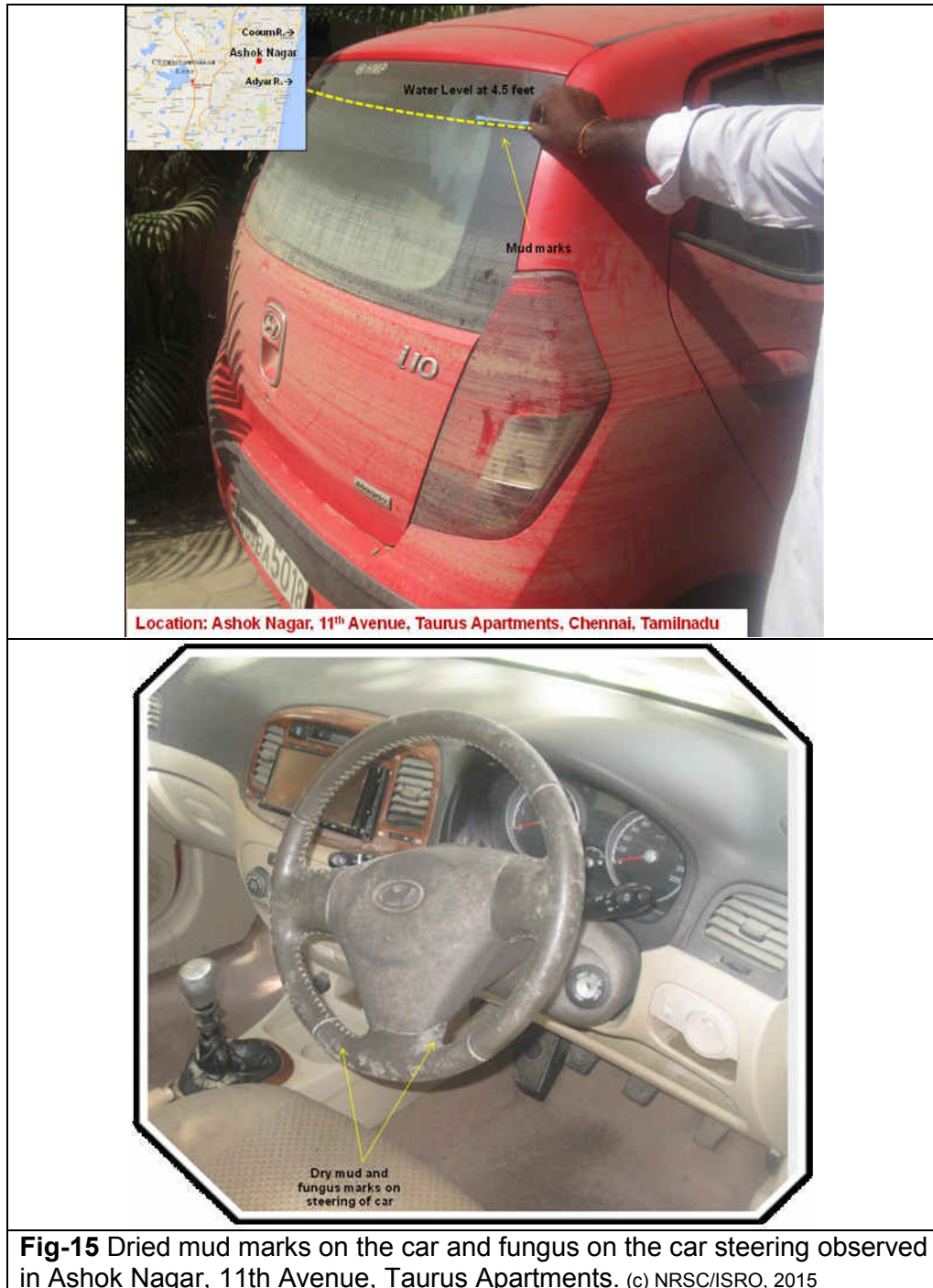
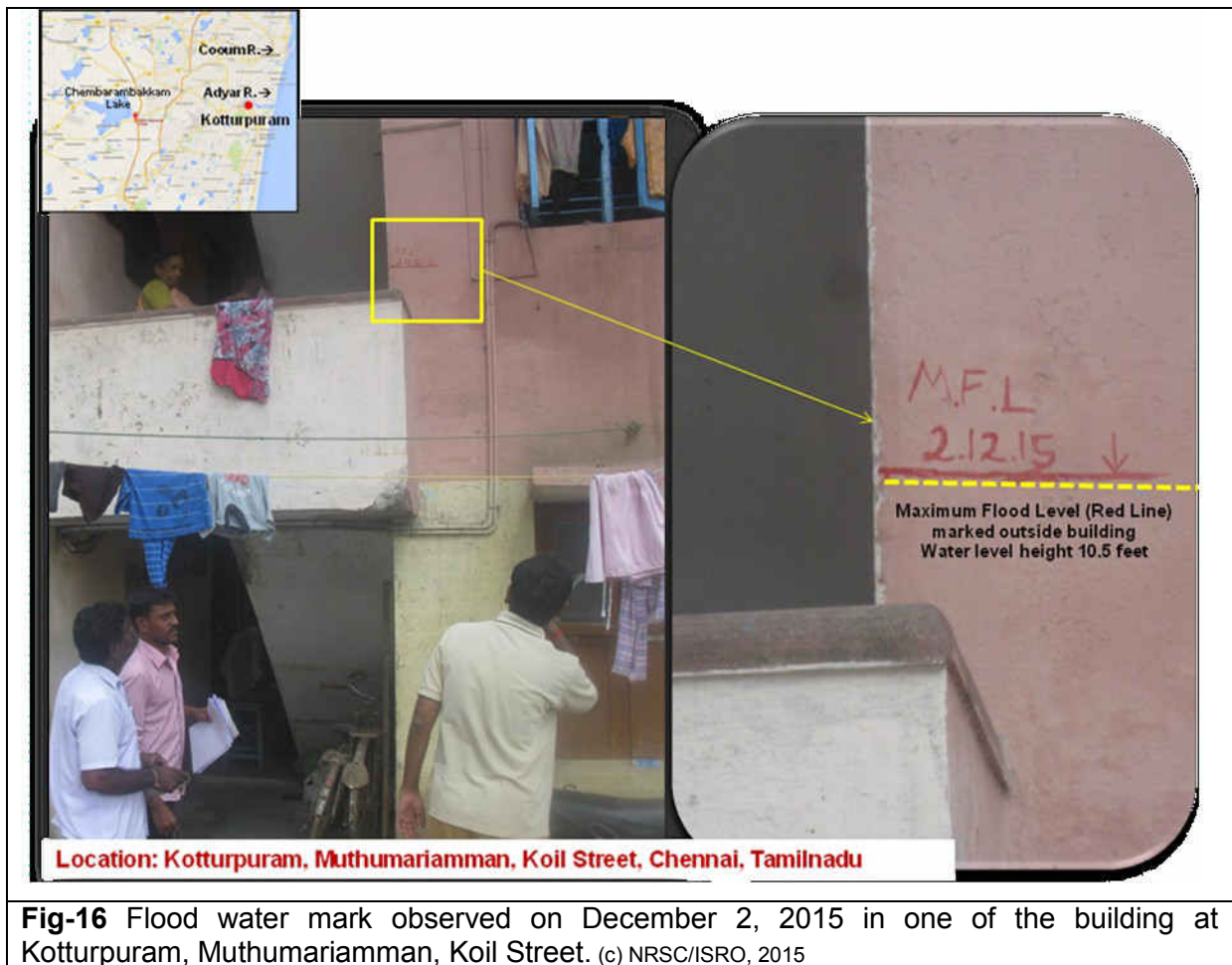


Fig-15 Dried mud marks on the car and fungus on the car steering observed in Ashok Nagar, 11th Avenue, Taurus Apartments. (c) NRSC/ISRO, 2015

Location 4: Kotturpuram (Chennai district)

Kotturpuram area is located 0.85km south of Adyar River and is one of the worse affected locations. Field inspection of one of the houses located in Kotturpuram (Chennai district) Muthumariamman, Koil Street it is observed that the flood water inundated upto 10.5 feet depth and flood water was there for three days before it started receding (Fig-16). The flood waters inundated ground floor of the building completely and partial inundation of the first floor. Due to flood waters all the household items especially electrical and furniture items were badly damaged.



Location 5: Velachery (Chennai district)

Velachery is a residential area in South Chennai, a metropolitan city in Tamil Nadu, India. The growth of Velachery during the last decade can be cited due to the growth of the IT sector in south Chennai. Velachery area is located about 2km south of Adyar River and is one of the worse affected locations. Flood water was stagnant in this area for almost 10 days causing maximum damage to houses located in this region. During field inspection the flood severity and flood waters persistence in this area could be observed from discolouration of the paint on doors, windows and meter boxes (wood made items) almost in all houses in Velachery (Fig-17, 18 & 19). The discoloration of the paint made a clear line indicating the depth to which the water had risen. Also the due to the submergence the water mark inside houses was also clear due to the moisture content well preserved. Average flood water depth observed was about 4.5-5 feet in this area. Due to flood waters all the household items especially electrical and furniture items were badly damaged (Fig-19). Waterlogging in many areas was observed during field visit in Velachery area (Fig-20).



Fig-17 Flood water mark observed in doors, windows and electric metre box due to discolouration in one of the houses at Plot 1, Venus Colony, Anna Nagar, 3rd Main Road, Velachery. (c) NRSC/ISRO, 2015



Fig-18 Flood water mark observed in doors, windows and electric metre box due to discolouration in one of the houses at Plot 30, Venus Colony, Anna Nagar, 2nd Street, Velachery. (c) NRSC/ISRO, 2015



Fig-19 Flood water mark observed in doors, inside house and damage to furniture in one of the houses in Venus Colony, Anna Nagar, 2nd Street, Velachery. (c) NRSC/ISRO, 2015



Fig-20 Waterlogged area in Venus Colony, Anna Nagar, Velachery. (c) NRSC/ISRO, 2015

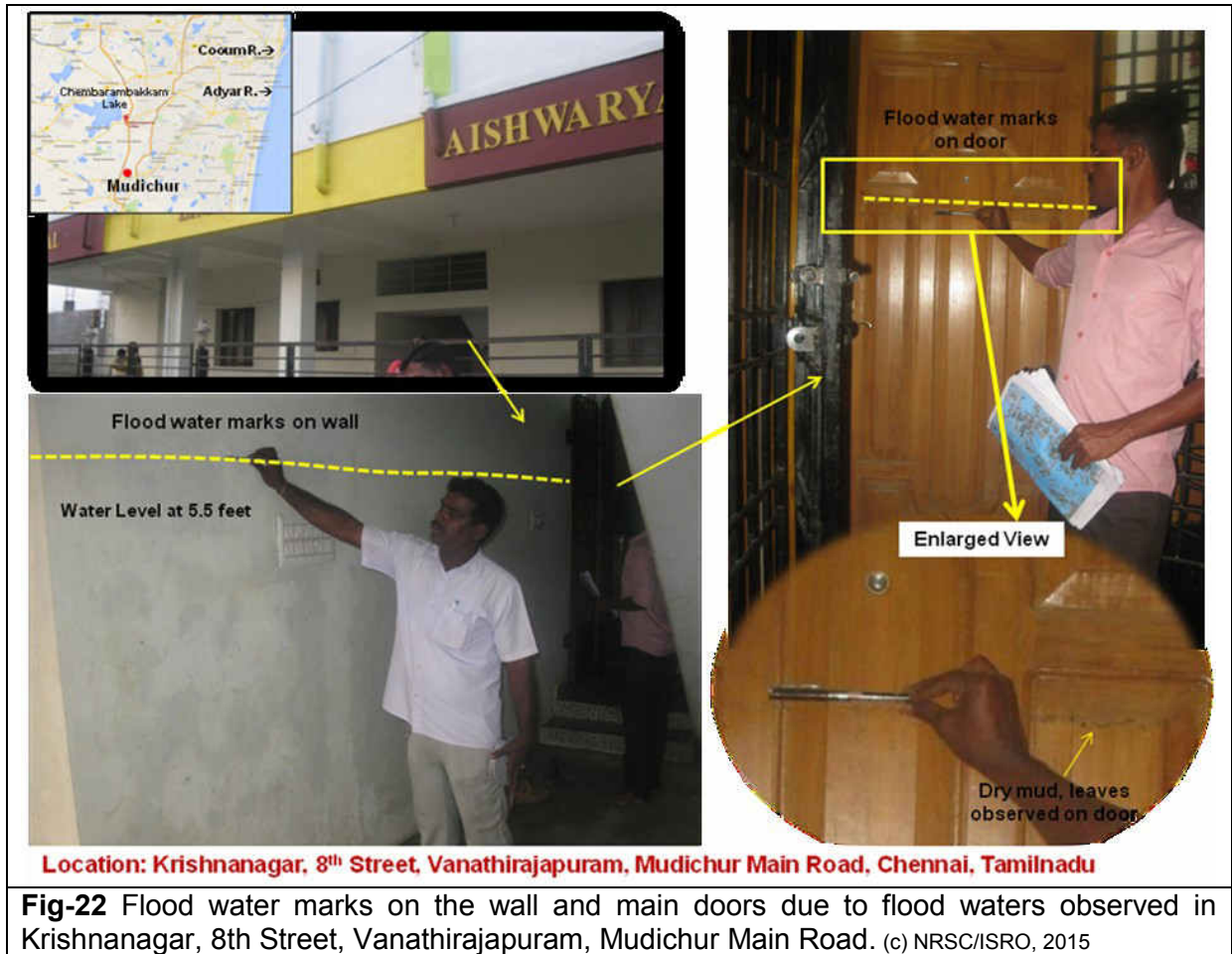
Location 6: Jafferkhanpet (Chennai district)

Jafferkhanpet is a locality of Chennai and Guindy, K.K. Nagar, Ashok Nagar, MGR Nagar, Saidapet is its neighbourhood suburbs. It is located about 0.2 km (aerial distance) north of Adyar River. Adyar River flowing below the Jafferkhanpet Bridge in this locality was in full spate with flood waters touching bottom of the bridge which must be at a height of about 20 feet. The wood, cloth and plastic pieces brought by the river can be seen clearly clinging on the bottom of the bridge alongwith water marks on the pillars supporting the bridge (Fig-21). The gushing flood waters had even damaged the road passing across the river and due to bank erosion side material caved in at many places blocking the flow of the water.



Location 7: Mudicur (Kanchipuram district)

Mudichur area is located about 6km south of Adyar River. Flood water marks on the wall and main doors could be seen at a height of 5.5feet. Here the water marks are visibke with the sediments and small twigs clinging on the door (Fig-22).



Location 8: Teynampet (Chennai district)

Teynampet is one of the busiest commercial localities in the city of Chennai. It is located about 2.5 km north of Adyar River. Here the average water depth in most of the houses was observed to be at 4.5 feet. Flood water marks inside the house walls could be prominently seen (Fig-23). This area was affected by flood waters on December 1, 2015 night and was under water for three days.

Location 9: Saidapet (Chennai district)

Saidapet is located about 0.5 km north of Adyar River. Here the water depth was observed in one of the house walls inside and also outside at about 6.5 feet. Flood water marks inside the house walls could be prominently seen here due to the moisture content (Fig-24). This area was affected by flood waters on December 1, 2015 night and was under water for 4-5 days.

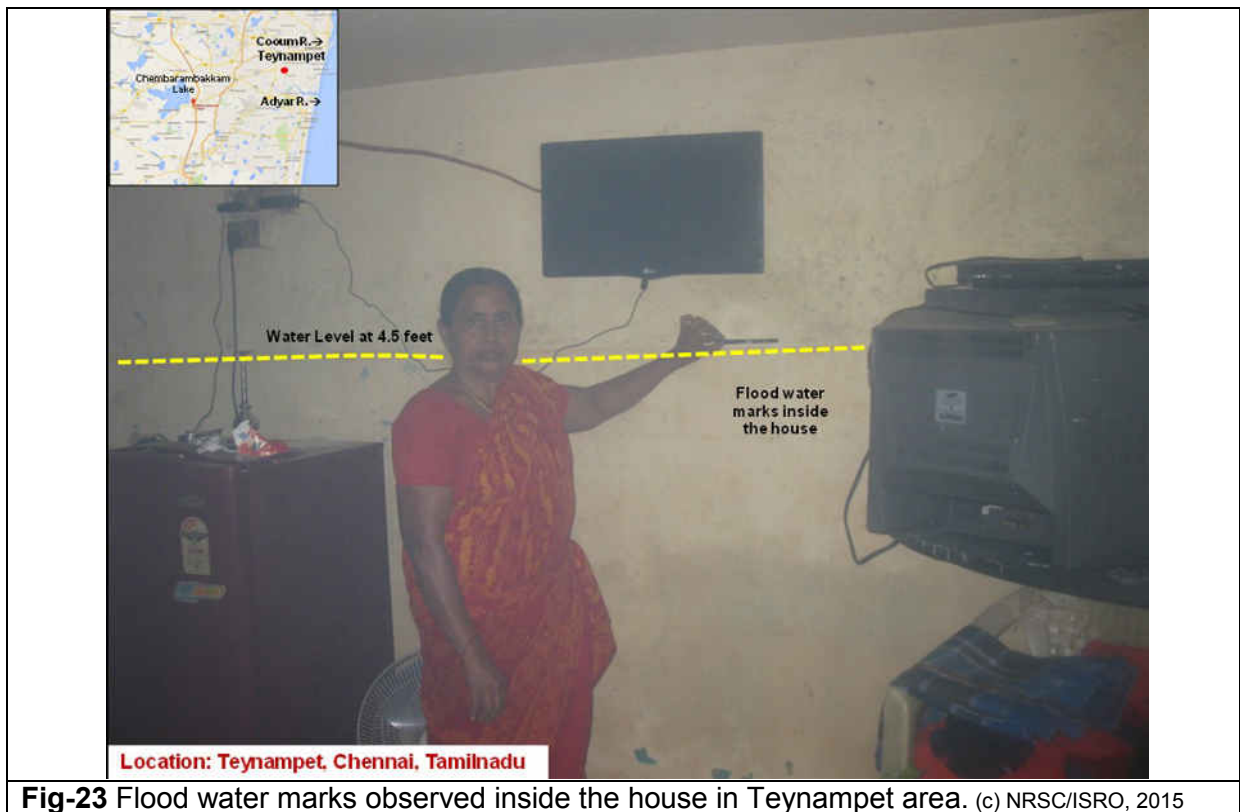


Fig-23 Flood water marks observed inside the house in Teynampet area. (c) NRSC/ISRO, 2015

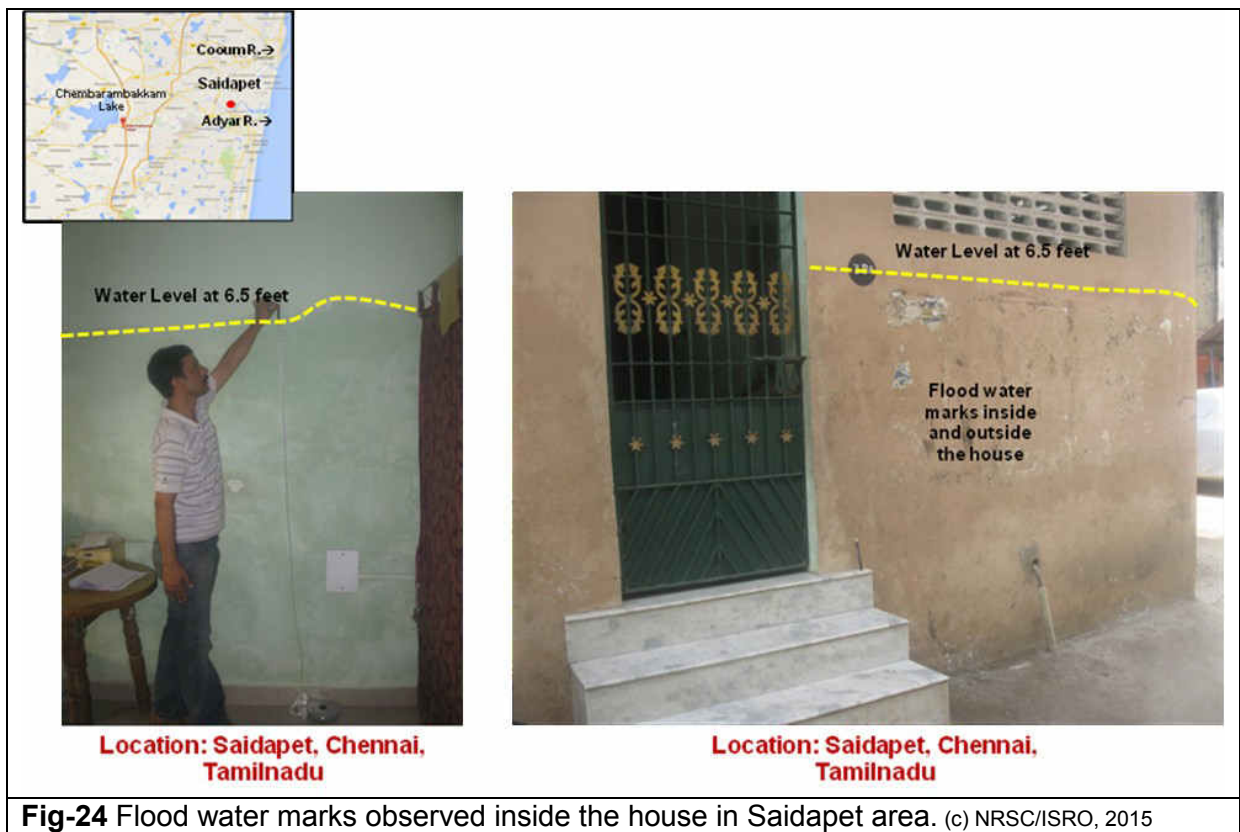


Fig-24 Flood water marks observed inside the house in Saidapet area. (c) NRSC/ISRO, 2015

Location 10: Pallavaram (Kanchipuram district)

Pallavaram is a town and a selection-grade municipality located in the suburbs of Chennai. It forms a part of the Alandur taluk of Kanchipuram district and is located 17 kilometres from Chennai city. Pallavaram is known for its cantonment and bustling residential colonies. Pallavaram is located about 3.0 km (aerial distance) south of Adyar River. Here the floodwaters were observed to be at 1 feet and not significant inundation was caused in this area. However due to heavy rains waterlogging and damage to boundary walls was observed in some places (Fig-25).



Fig-25 Collapsed boundary wall of ISRO Guest House at Pallavaram area. (c) NRSC/ISRO, 2015

Location 11: Vandalur (Chennai district)

Vandalur is a census town and is a locality in the south of Chennai in Kancheepuram district. Vandalur is called Entrance Gate for Chennai city. It is located about 0.2 km (aerial distance) north of Adyar River. In this area the houses were seen inundated to depth of 2.5 to 3.0 feet (Fig-26).

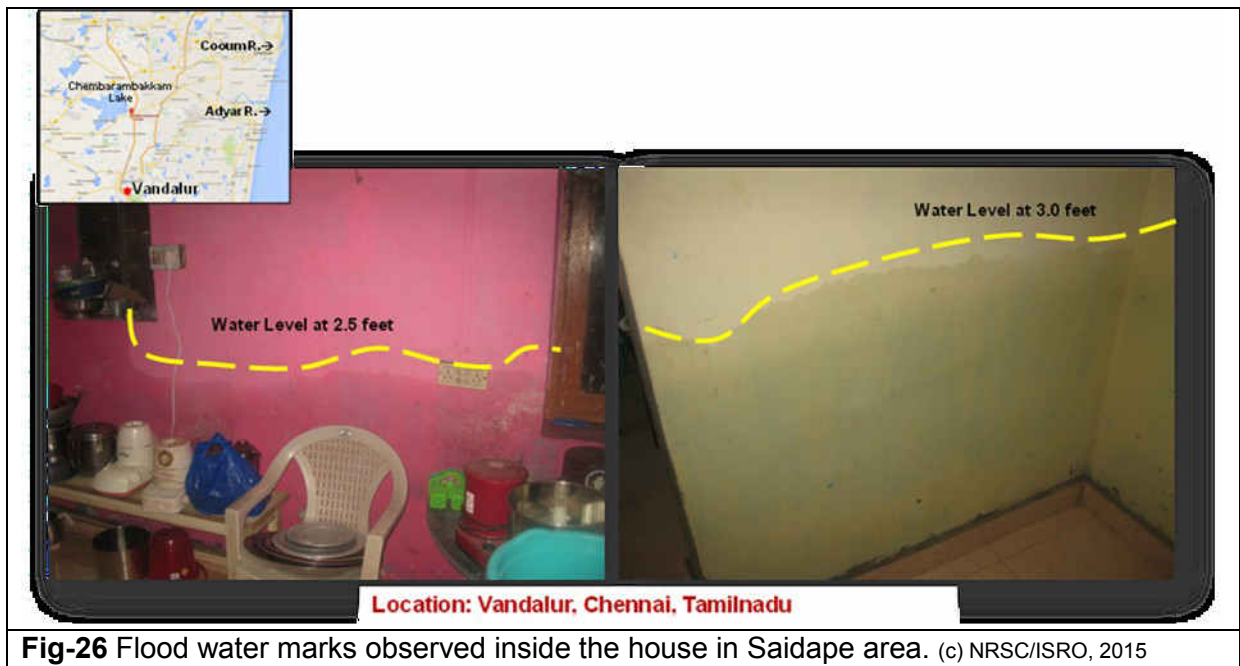


Fig-26 Flood water marks observed inside the house in Saidape area. (c) NRSC/ISRO, 2015

5.0 Geovisualization on Bhuvan Portal

The locations visited on ground (Fig-10) and the information collected on the flood depth and damage using Bhuvan App was uploaded onto ISRO's Bhuvan Portal for spatial visualization and wider access (Fig-27 to Fig 31).

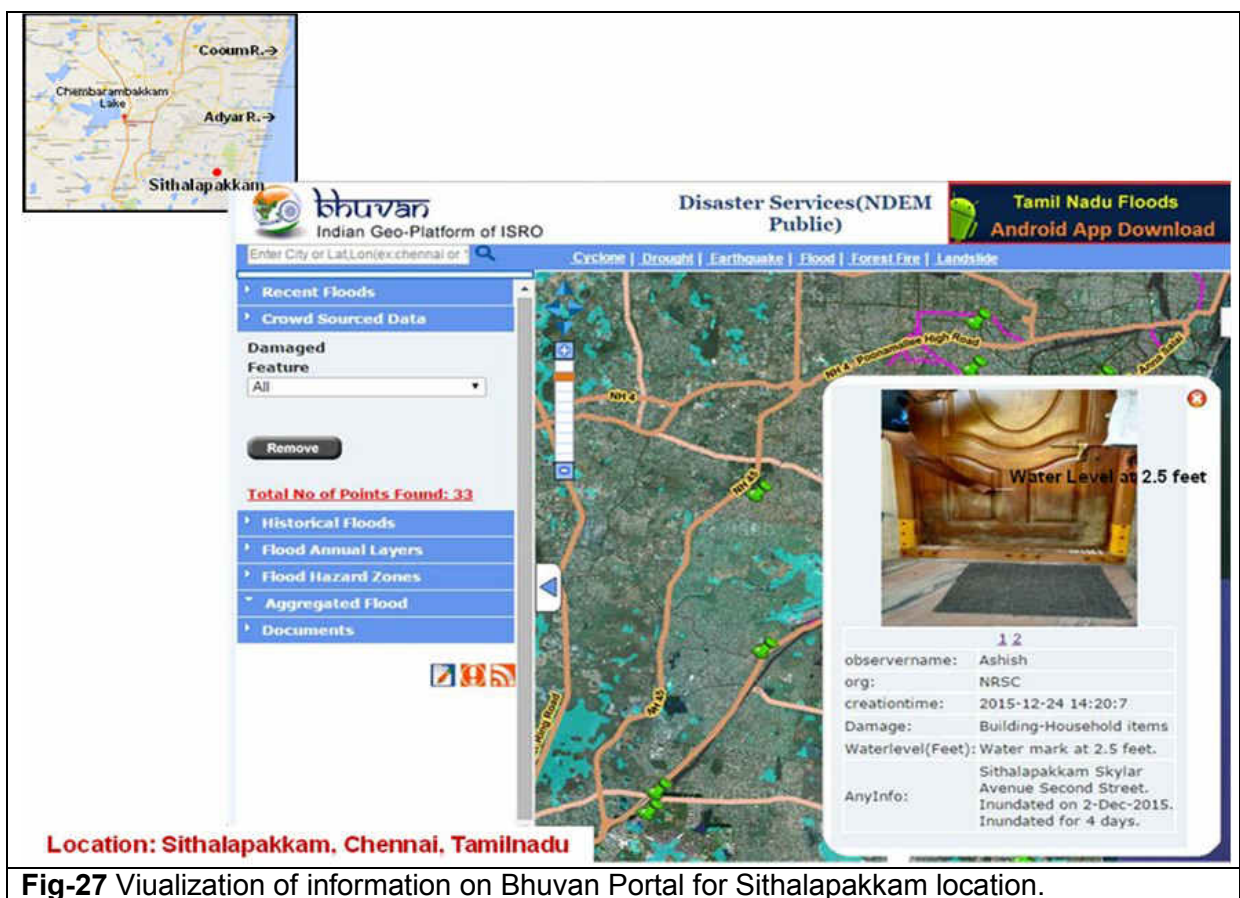


Fig-27 Visualization of information on Bhuvan Portal for Sithalapakkam location.

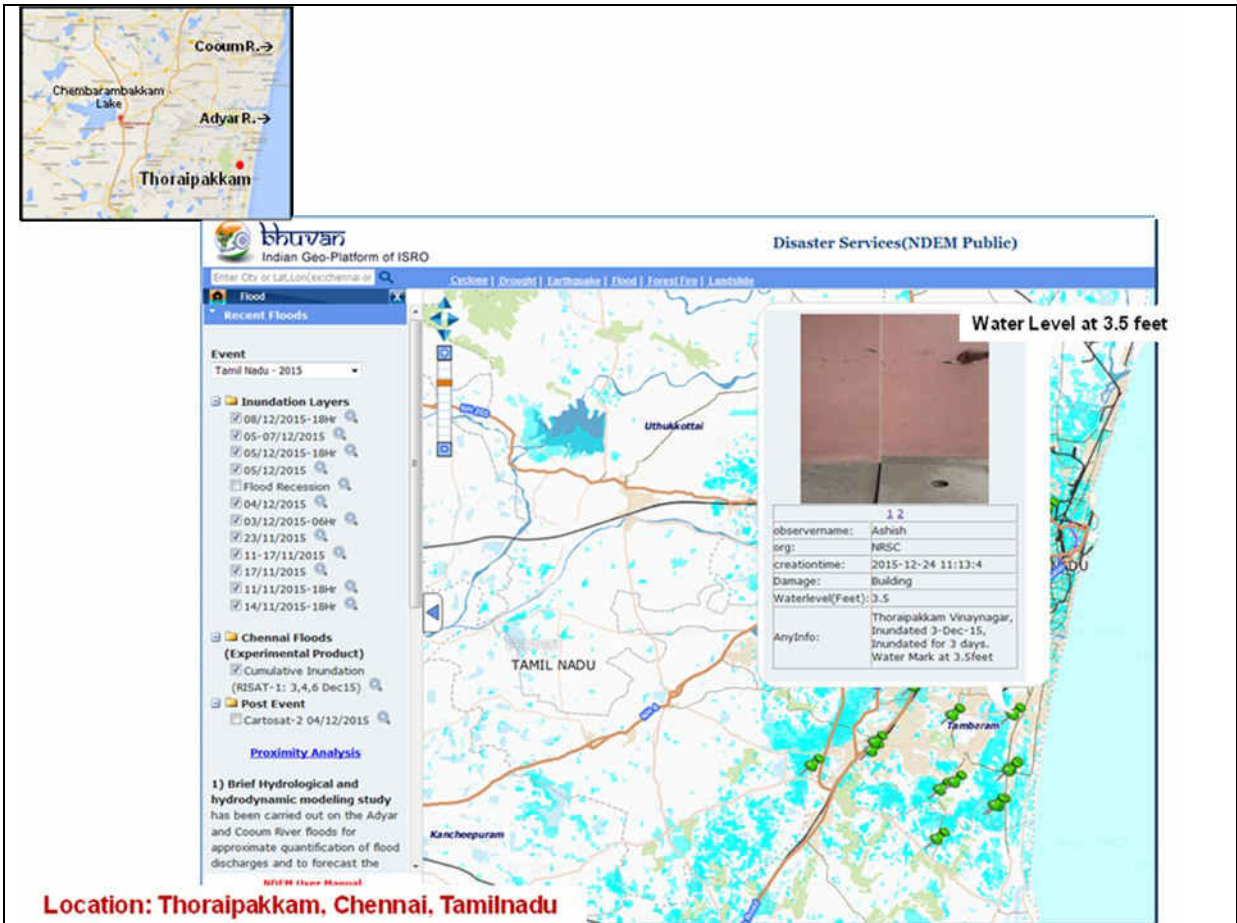


Fig-28 Visualization of information on Bhuvan Portal for Thoraipakkam location.

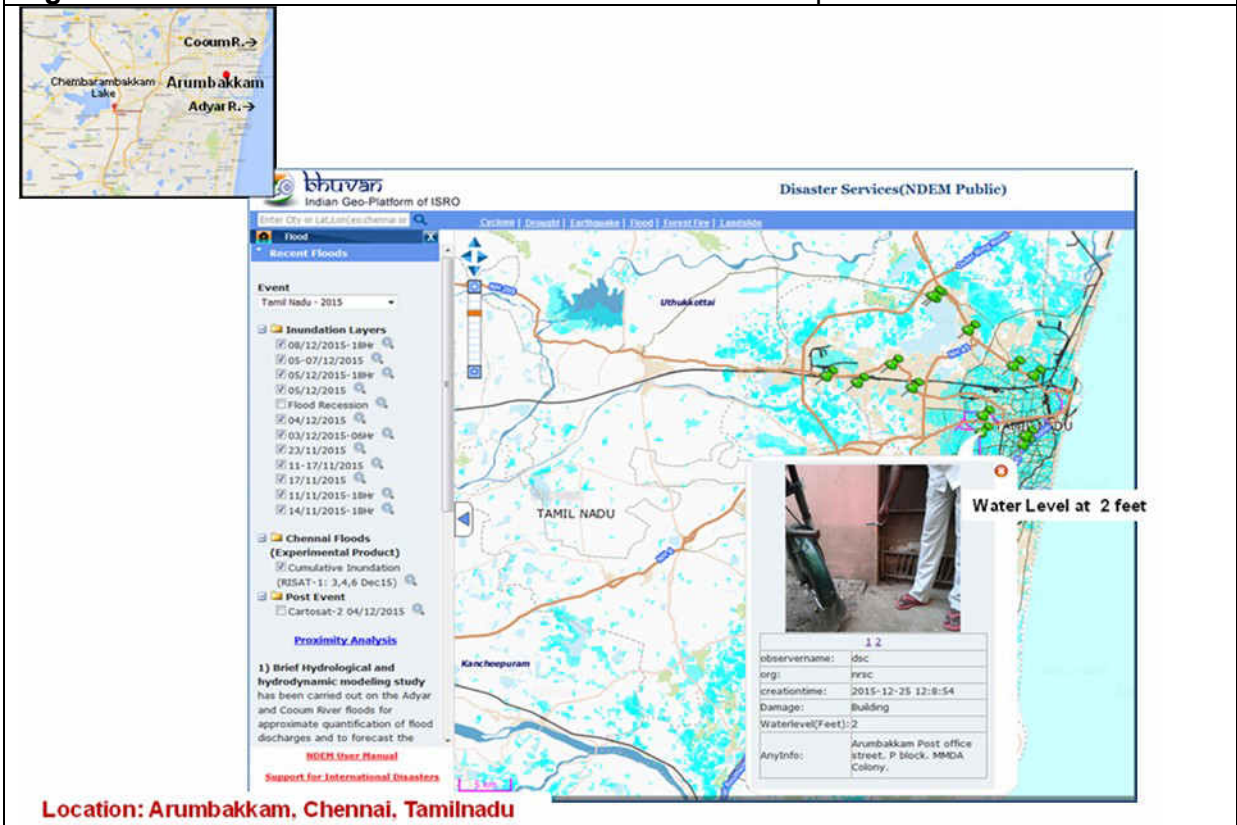
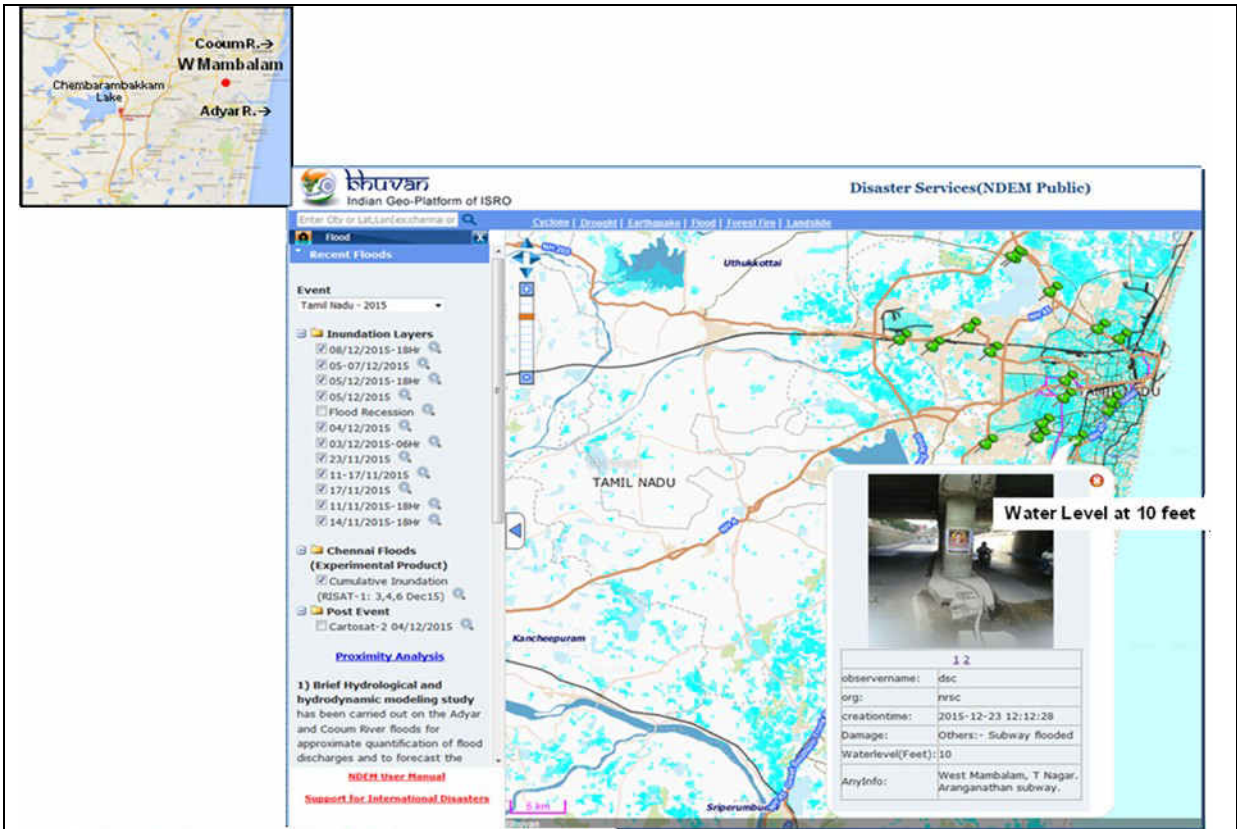
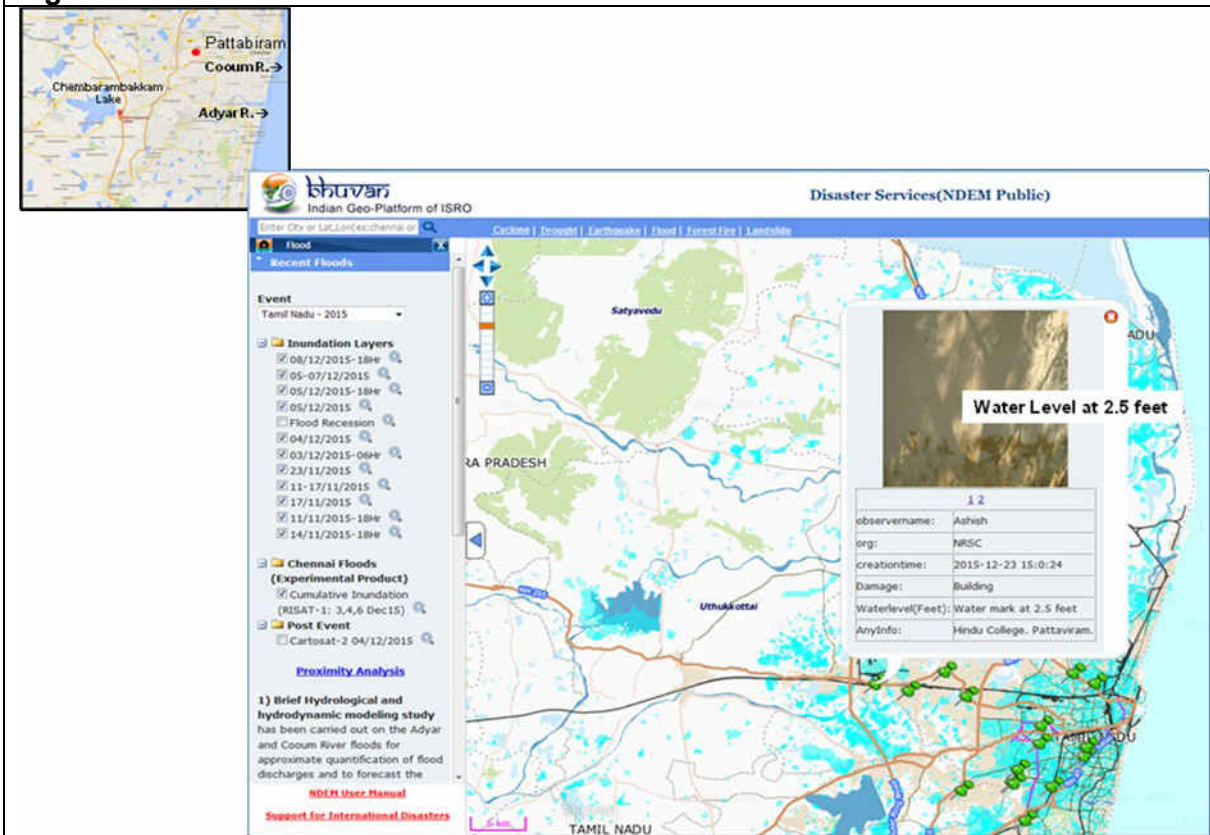


Fig-29 Visualization of information on Bhuvan Portal for Arumbakkam location.



Location: West Mambalam, Chennai, Tamilnadu

Fig-30 Visualization of information on Bhuvan Portal for West Mambalam location.



Location: Pattabiram, Chennai, Tamilnadu

Fig-31 Visualization of information on Bhuvan Portal for Pattabiram location.

6.0 Results and Discussions

- From the field survey and interaction with local people it is observed that the entire Chennai city was affected due to the heavy rains and flood waters. Fig-32 shows the overview of flood depth observed in locations visited in Chennai, Thiruvallur and Kanceepuram districts. Fig-33 shows the detailed map of flood depth along with locations name along Adyar River. Fig-34 shows the interpolated flood depth map based on field based collected information for parts of Chennai, Thiruvallur and Kanceepuram districts.
- Severity of this event could be assessed from the fact that the field survey being carried out after 3 weeks of the event also the moisture marks within the houses and flood water marks outside the building were well preserved and clearly visible.
- Severe damage to household items like electrical equipments, furniture, clothing, bedding, books and vehicles being submerged by flood waters was visible in all areas visited.
- South of Chennai overflowing waters from Adyar River into adjoining low-lying areas created flooding problem whereas north of Chennai rain water accumulation in low lying areas caused more problem.
- Major flood inundation and damage to residential buildings was observed in areas adjoining the Adyar River and localities like Manapakkam, Kotturpuram, Teynampet, Menambakkam, Annannagar, and Velachery were severely affected (Fig-7).
- Flood water depth was observed to be as high as 11.5 feet near Manapakkam, 10.5 feet at Kotturpuram and 6.5 feet near Saidapet (Fig-33).
- Flood water persistence in localities located south of Adyar River particularly in central part of Chennai was more than 10 days and water had to be removed through pumping.
- Velachery is one of those localities where water persisted for more than 10 days and average flood water depth in this area was about 4.5-5.5 feet. Colonies like Baby Nagar, Anna Nagar Extension and Venus Colony were worse affected. The discoloration of all houses doors and windows located in these localities due to stagnated water made the flooding impact distinct in this area (Fig 17-20).

- Areas adjoining Cooum River were not so severely affected except rain water accumulating in low lying areas (Fig-8) and the average flood depth in these areas from field based information was about 1-2 feet (Fig-34).
- This catastrophic event not only caused economic losses but psychological impact of this event was well evident during interactions carried out with local people staying in houses inundated by flood waters. People in the flooded zones had vacated the ground floors in fear of any such repeat of event.

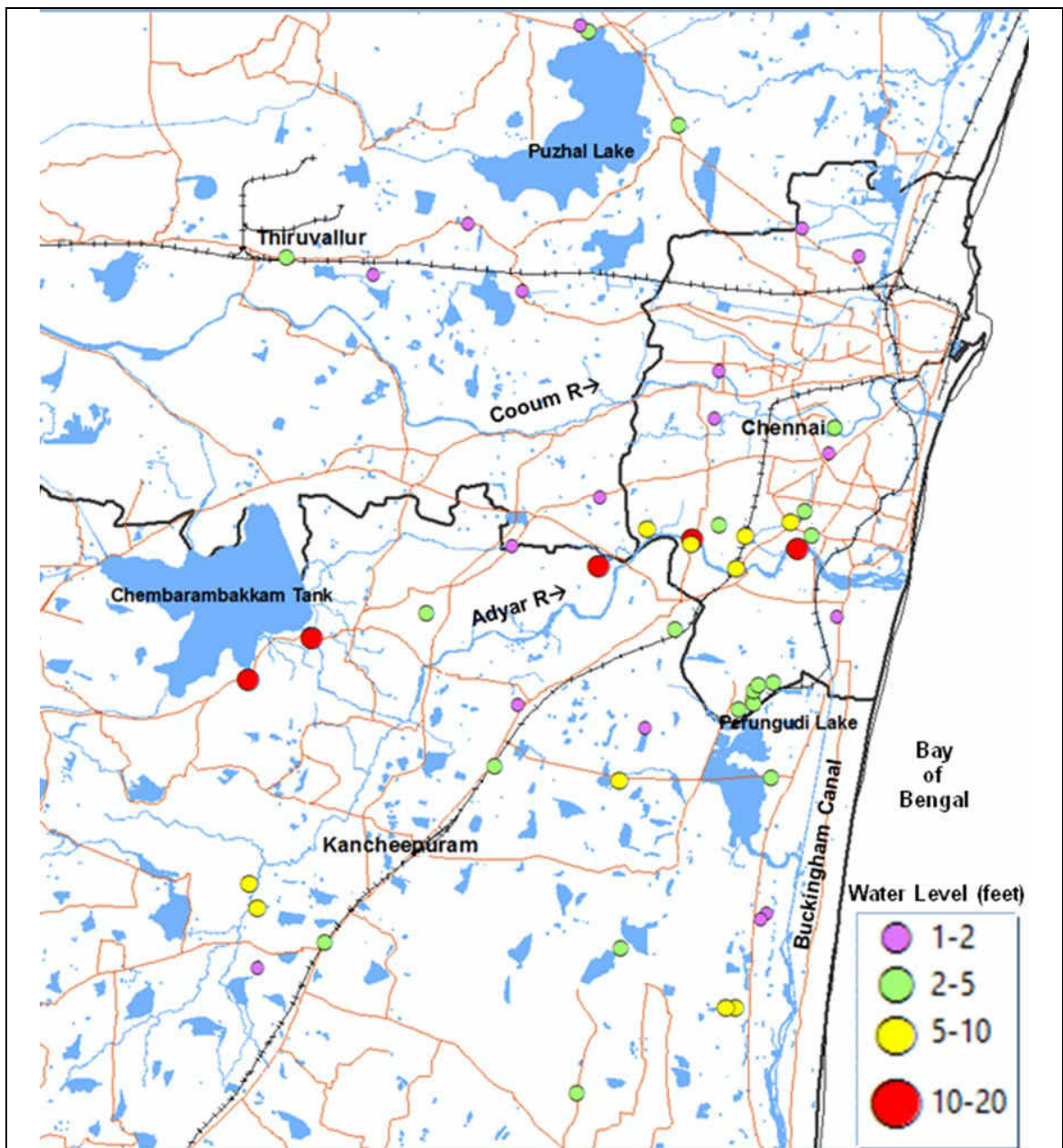


Fig-32 Map showing depth of flood waters collected during field from Chennai, Thiruvallur and Kancheepuram districts.

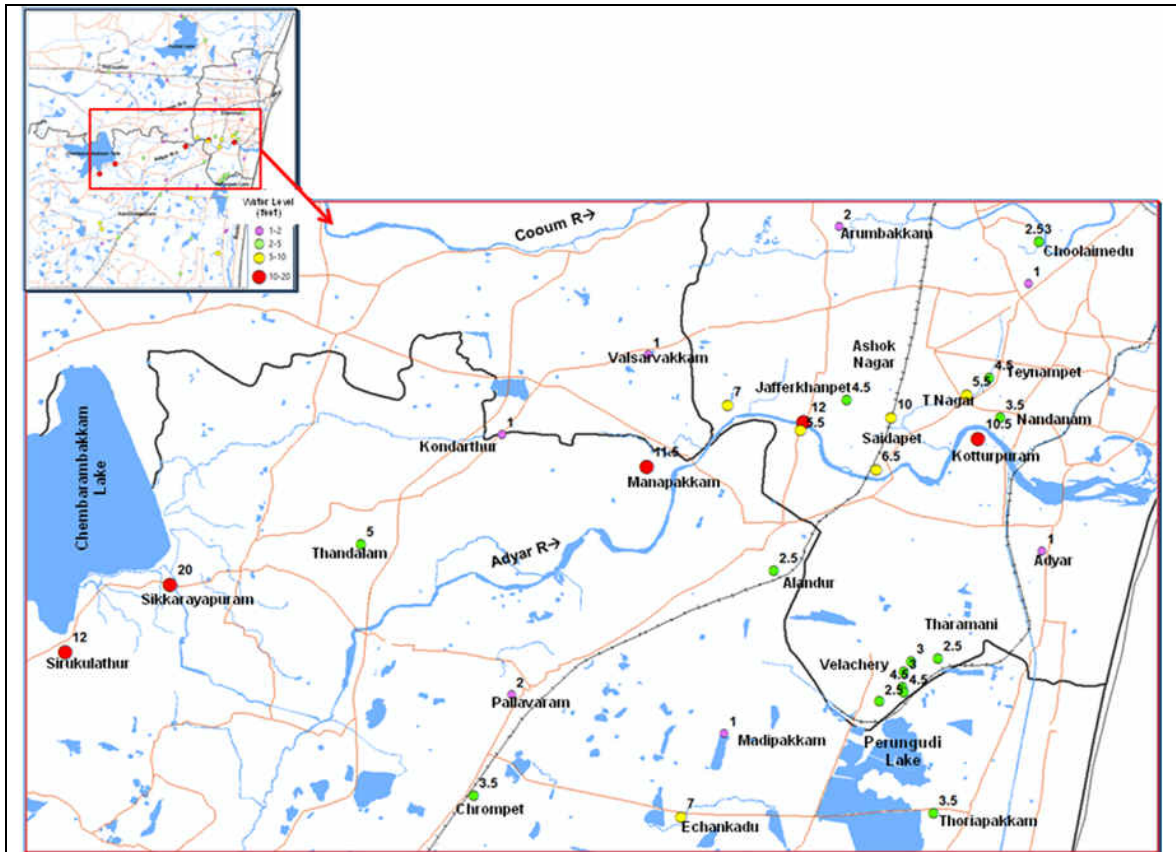


Fig-33 Detailed view of flood water depth observed in areas adjoining Adyar River.

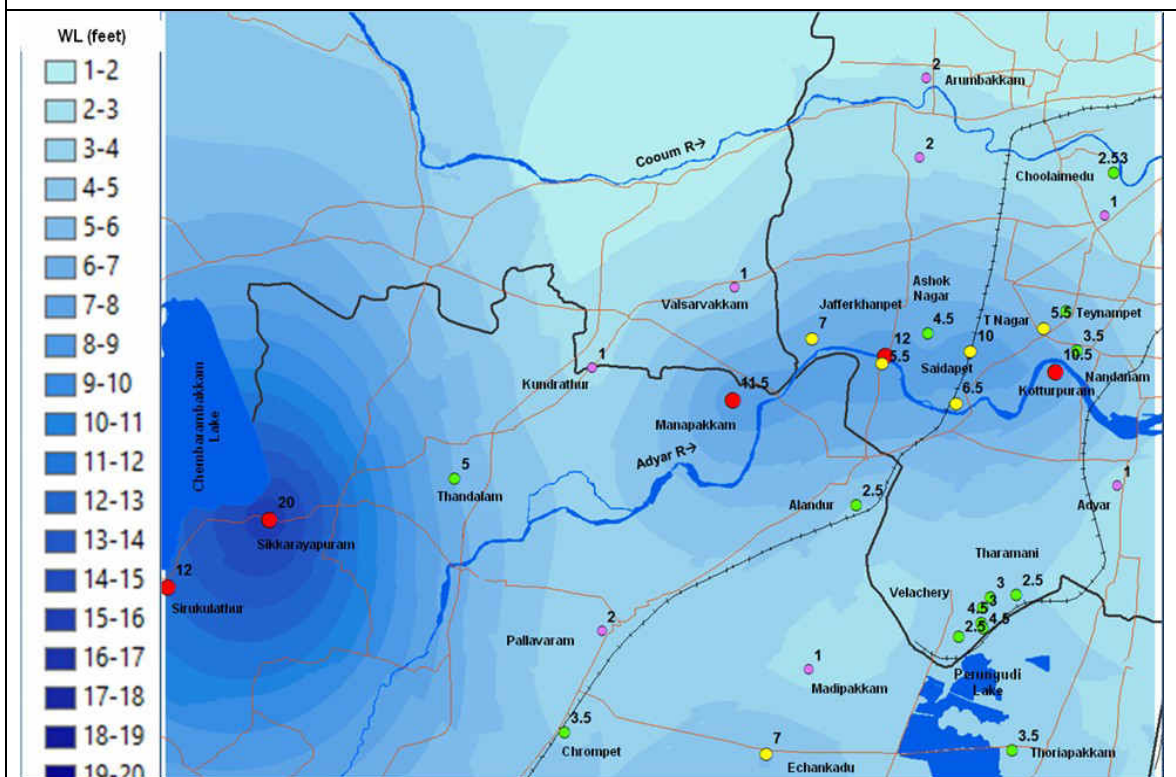


Fig-34 Flood depth map based on field data collected for parts of Chennai, and adjoining areas.

7.0 Conclusions

- From the field experience and also interaction with local population it has been observed that the urbanization and encroachments of river banks, marshy, low-lying areas especially Adyar River has aggravated the flooding problem. The narrow and constrained river with no flood plains left could not carry the discharges and water simply occupied the adjoining low-lying areas. A study carried out by Chandan et.al. (2014) on analysis of land use change pattern in past 4 decades shows that the total urban area has been increased by more than 20 times mainly from the conversion of grazing, agricultural and open areas to urban impervious surface. They have observed that Vegetation cover has dramatically decreased from 70.47% in 1991 to 35.53% in 2013, whereas the non-vegetation i.e. built up, paved areas etc. have increased 29.53% in 1991 to 64.47% in 2013.
- Chennai floods have once again highlighted the urban flooding problem and has stressed the fact that the urbanization needs to be done keeping in account the geomorphology, hydrology and land use of the area.
- Flat topography of Chennai area makes difficult for the flood waters to drain out quickly and hence there is a need for proper drainage management.
- Management of reservoirs, revival of wetlands which act as as a 'sponge' to absorb the excess water and resizing of the storm water drains keeping in account the present and projected population should be taken as mitigative measures.
- Based on 2015 floods experience flood hazard plain zoning needs to be done for future expansion of the city and assessing the threat to habitation living in various municipal zones for better prpreparedness.

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Annexure 1 : List of locations for which information on flood depth, flood persistence and field photograph of flood water marks was collected during field visit

Location	Water Level (feet)	Inundated On	Flood Persistence	District
Teynampet (Alamman Kovil Street)	4.5	1-Dec-15	4 days	Chennai
Arumbakkam (Post Office Street)	2.0	2-Dec-15	3 days	Chennai
Ashok Nagar (Taurus Apartments)	4.5	2-Dec-15	3 days	Chennai
Jafferkhanpet (Bridge)	12.0	1-Dec-15	3 days	Chennai
VGP Selvanagar Extn (Plot 79)	2.5	1-Dec-15	4 days	Chennai
Anna Nagar (Venus Colony, Plot-1)	4.5	1-Dec-15	7 days	Chennai
Annai Indranagar (Vanchinathan Street))	3.0	1-Dec-15	4 days	Chennai
Tharamani (Babynagar)	3.0	1-Dec-15	3days	Chennai
Adyar (Antariksha Vihar)	1.0	1-Dec-15	3 days	Chennai
Nandanam (Turn Bulls Street)	3.5	1-Dec-15	4 days	Chennai
West Mambalam (Arangnathan Subway)	10.0	2-Dec-15	3 days	Chennai
Thousand Lights (Middle School)	1.0	1-Dec-15	5 days	Chennai
Thousand lights (Police Quarters)	3.0	1-Dec-15	3 days	Chennai
Choolaimedu	2.5	1-Dec-15	3 days	Chennai
Anna Nagar (Shanti Colony)	2.0	1-Dec-15	3 days	Chennai
Thirumullaivoyal (KK Nagar)	1.5	1-Dec-15	3 days	Chennai
Sholinganallur (Anna Street)	2.0	3-Dec-15	2 days	Chennai
Vyasarpadi	1.5	2-Dec-15	8 days	Chennai
Thoraipakkam (Vinay Nagar)	3.5	3-Dec-15	3 days	Chennai
Sholinganallur (Sacred Heart School)	2.0	3-Dec-15	2 days	Chennai
OMR Rajiv Gandhi Salai (Satyabhama University)	6.0	16-Nov-15	20 days	Chennai
OMR Road	6.0	16-Nov-15	20 days	Chennai
Mambakkam	3.3	1-Dec-15	3 days	Chennai
Ekkaduthangal (Jawahar Nehru Street)	5.5	2-Dec-15	4 days	Chennai
Samayapurathu Mariamman	7.0	3-Dec-15	3 days	Chennai
Saidapet (Salavaiyalar Colony)	6.5	1-Dec-15	4 days	Chennai
Kotturpuram (Muthumariamna Kovil Street)	10.5	1-Dec-15	3 days	Chennai
Valsaravakkam (Kamraj Street)	1.0	1-Dec-15	2 days	Chennai
Manapakkam (SRCM Hqtrs)	11.5	1-Dec-15	10 days	Chennai
Chrompet (Radha Nagar)	3.5	1-Dec-15	3 days	Chennai
Vardharajapuram (Krishna Nagar)	6.0	1-Dec-15	3 days	Chennai
Anna Nagar (Venus Colony Plot 30)	4.5	1-Dec-15	7 days	Chennai
Tharamani (Bharathi Nagar)	2.5	1-Dec-15	3 days	Chennai
T Nagar (Thomas Road)	5.5	1-Dec-15	4 days	Chennai
Vandalur (Mooggambigai Koil Street)	2.5	1-Dec-15	7 days	Kancheepuram
Mudichur	5.5	1-Dec-15	3 days	Kancheepuram

Mannivakalam.	1.0	1-Dec-15	3 days	Kancheepuram
Echankadu (.Anna Nagar)	7.0	1-Dec-15	5 days	Kancheepuram
Thandalam	5.0	2-Dec-15	4 days	Kancheepuram
Sithalapakkam (Skylar Avenue)	2.5	2-Dec-15	4 days	Kancheepuram
Sikkarayapuram (Madha Engg College)	20.0	1-Dec-15	3 days	Kancheepuram
Sirukulathur	12.0	1-Dec-15	3 days	Kancheepuram
Kundrathur	1.0	1-Dec-15	2 days	Kancheepuram
Pallavaram (ISRO Guest House)	2.0	1-Dec-15	2 days	Kancheepuram
Madipakkam (Sabari Salai)	1.0	1-Dec-15	2 days	Kancheepuram
Ambattor (Sivananda Nagar)	1.5	1-Dec-15	3 days	Thiruvallur
Avadi (TNHB Road)	2.0	1-dec-15	3 days	Thiruvallur
Erukkancheri (AP Arasu Street)	1.0	1-Derc-15	3 days	Thiruvallur
Pattabhiram (Hindu College)	2.5	1-Dec-15	2 days	Thiruvallur
Puzhal (GNT Road)	2.5	10-Nov-15	20 days	Thiruvallur
Alandur (VOC Nagar Street)	2.5	2-Dec-15	4 days	Thiruvallur
Redhills	4.0	10-Nov-15	20 days	Thiruvallur
Gandhi Nagar	2.0	10-Nov-15	20 days	Thiruvallur
<i>Information presented is based on data observed and collected form intraction with local people during field survey</i>				

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