Mapping of water logged areas using SAR images to assess the impact of Tropical Cyclone Gaja in Nagapattinam district, Tamil Nadu using Remote Sensing and GIS

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Abstract: The strong wind, heavy rain and large storm surge associated with tropical cyclones are the factors that eventually lead to loss of life, property and infrastructure in many coastal areas of the world. Data from Synthetic Aperture Radar (SAR) is an effective way to detect flood due to heavy rain and to monitor the changes in water bodies over large areas as radar has the competence to operate under all weather conditions at any time. Based on the backscattering effect, water logged areas can be separated from non-water bodies. This paper reviews about the impact of tropical cyclone Gaja in Nagapattinam district of Tamil Nadu with specific focus on the identification as well as mapping of stagnant water due to heavy landfall using SAR data. The study also investigated the impacts of the cyclone based on waterlog areas such as the extent, the duration and the affected land features including settlement areas due to cyclone. The outcome of the study would be particularly significant to plan and execute rescue operations for emergency response during flood. Quantitative and qualitative measures can be derived from the analysis of SAR data in Sentinel Application Platform (SNAP) in order to assess the extent of the damage caused from flood inundation. The study integrated the application of SAR and Multispectral Scanner System (MSS) temporal data for better understanding and assessment of the damaged areas. Based on the study, the waterlogged area due to cyclone was about 5532 hectares with prolonged water stagnation on agriculture and settlement areas of about 993 hectares and 597 hectares for about 101 days. About 493 hectares of plantation were assessed to be damaged due to cyclone. Ecologically Sensitive Areas (ESA) such as mudflats in the lagoon area and mangroves along Vedaranyam coast were among the affected land features.

Keywords: SAR, Sentinel-1, Gaja tropical cyclone, waterlog areas, impacts, damage assessment, SNAP, MSS data

1. INTRODUCTION

Cyclone is a large low-pressure region with circular wind motion. The normal areal extent of a cyclone is about 100-200 km in diameter. The center of the storm, called the eye, will be relatively quiet while outside the eye, very strong winds reaching to as much as 200 km/hr exist. Generally wind speed gradually decreases towards the outer edge. The rainfall will normally be heavy in the entire area occupied by the cyclone. Tropical cyclones cause heavy damage to life and property on their land path associated with intense rainfall and heavy floods. They have greater impacts on agriculture and infrastructures such as shelter, sanitation, drinking water, electricity supplies and transportation services. The damages caused by winds were extensive and cover areas were mostly larger than the areas of heavy rains and storm surges which were in general localized in nature.

1.1 Water Logging

Soil is indicated to be water logged when it is completely saturated with water, which is caused by water stagnation on flat land and low lying areas over a longer period. Excess rainfall can lead to water logging of soils, the duration of which varies greatly depending on the amount of rain, evapotranspiration and soil structure. Another impact is that when water dries, salts accumulate on the soil surface resulting in salinity. When cultivable land is waterlogged, salinity causes destruction of vegetation and crops (National Commission on Agriculture, 1976 [10]). Multi spectral and multi temporal satellite data have potential to delineate and map waterlogged areas (Pandey et al. 2010 [11]), especially microwave remote sensing offer prominent way to delineate flood and water logging (Suraj Kumar Singh, 2017 [14]).

1.2 Synthetic Aperture Radar (SAR)

Synthetic Aperture Radar, are active sensors fixed on satellites that emit a radar pulse and record the emitted or reflected pulse from the land surface. With the help of the longer wavelength, SAR penetrates the cloud cover (Schumann et al. 2009 [13]). SAR owns the ability to collect data at night time (Alsdorf et al. 2007 [1]; Schlaffer et al. 2015 [12]) and at any weather conditions that makes it ideal for flood mapping (Hostache et al. 2012 [8]). Radar return strength is based on surface roughness, dielectric properties and local topography in relation to the radar look angle (Brivio et al. 2002 [2]; Gan et al. 2012 [5]). As a specular reflector, calm water bodies seem very dark in microwave images as stagnant water directs all the backscatter radiation away from the sensor (Suvrat Kaushik, 2019 [15]). Water surface roughness, due to heavy rainfall or wind, results in backscattering of the radar signal, increasing the possibility of inundated areas not being highlighted (Alsdorf et al. 2007[1]; Jung et al. 2010 [9]). Radar shadow due to side looking property of Radar and the double bouncing effect of the signal, sometimes make difficulty in interpreting SAR image for water body delineation (Horritt et al. 2001 [7]; Jung et al. 2010 [9]; Giustarini et al. 2013 [6]). Single image analysis and change detection approach were the two most used methods to extract waterlogged area with the SAR images (Chang Liu, 2016 [3]).

2. STUDY AREA

Nagapattinam district was considered as the study area since it fell directly in the track of cyclone Gaja and maximum damage was reported in this coastal district. It lies on the shores of the Bay of Bengal between latitude 10.79°N and longitude 79.84°E. The district comprises of eight taluks of which 5 are coastal as shown in Fig.1. Though the entire district was severely affected by Gaja Cyclone, southern Nagappattinam district was the core region devastated the most by the cyclone as shown by the Zone of Influence of the cyclone in Fig.1. Hence the attempt to determine the objected aim of the paper was applied to the four taluks of southern Nagappattinam district namely Nagappattinam, Thirukuvalai, Kilvelur and Vedaranyam.

Cyclone Gaja

Gaja was a very severe cyclonic storm (Fig.2) that made a landfall over Tamilnadu coast from 16th to 19th November, 2018. The wind speed at the time of landfall was about 120–140 km/hr and heavy rainfall (Annex I) leaving behind a huge trail of destruction in the districts of Nagapattinam, Cuddalore, Thanjavur, Tiruvarur, Pudukottai, Dindigul, Trichy, Karur, Sivagangai, Ramnad and Karaikal a Union territory of Puducherry (Fig.3).

It was reported that about 45 people died, mostly in the districts of Nagappattinam, Thiruvarur, Thanjavur, and Pudukottai. Thousands of cattle and birds died due to the cyclone. About 13,000 hectares of crop lands and plantations were reported to be damaged.

3. DATA SOURCE

Sentinel satellites provide data with high spatial and temporal resolution (Clement et al. 2018 [4]). The Sentinel-1 mission comprises a constellation of two polar-orbiting satellites, operating day and night performing C-band Synthetic Aperture Radar (SAR) imaging, enabling them to acquire imagery regardless of the weather. The SAR system operates within C-band (5.407 GHz) frequencies in one of four acquisition modes: Stripmap (SM), Interferometric Wide swath (IW), Extra-Wide swath (EW), and Wave (WV). IW is the default mode for land cover acquisition (Chang Liu, 2016 [3]). Sentinel 1A data pertaining to pre and post cyclone were used for the present study. As the cyclone made landfall on 16th November 2018, Sentinel data of 8th and 20th November, 2018 were used for pre and post cyclone analysis as shown in Table 1. To assess the duration of waterlog and their damage impacts, Sentinel data of 24th February 2019 was considered as that was the first image indicated return of almost normal environment post cyclone. The details of the SAR images considered for the study were tabulated in Table 1.

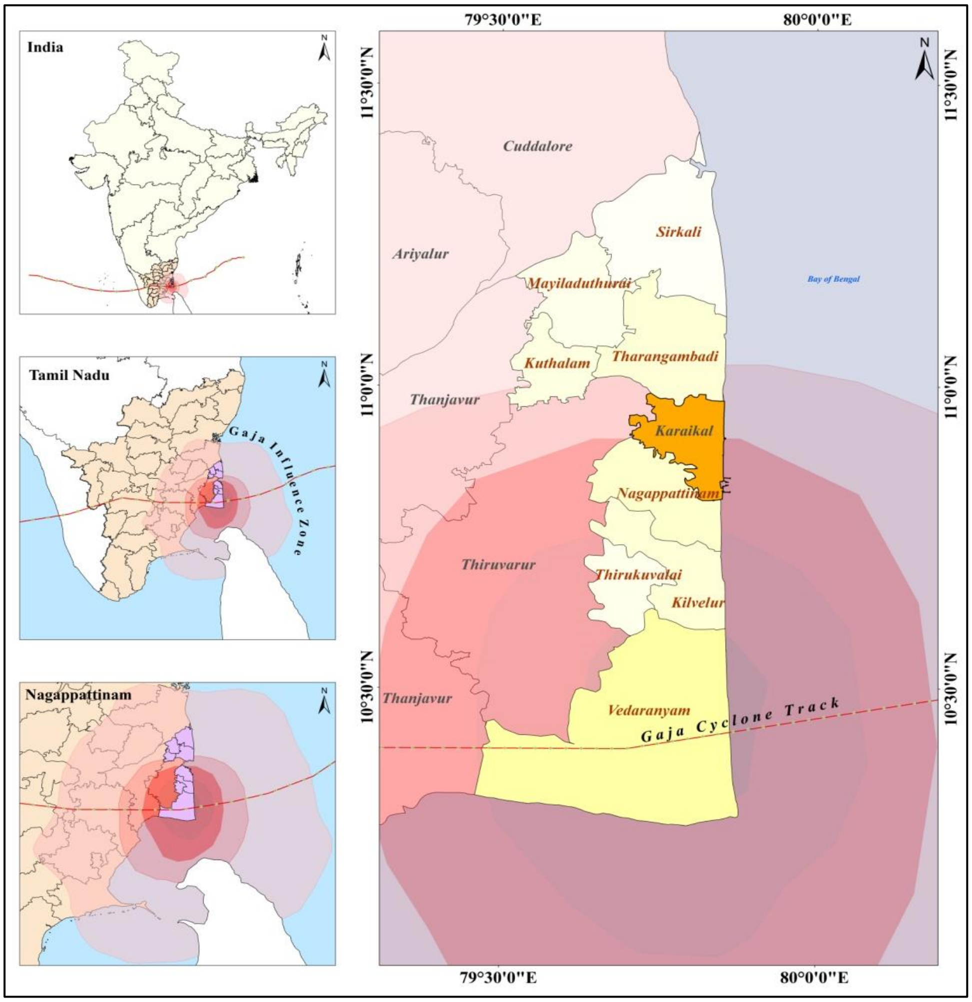
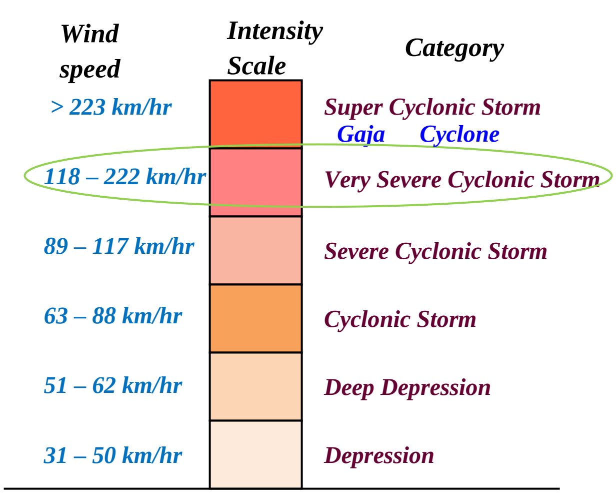


Fig-1: Study area with Gaja cyclone influence zone (*Source: IMD*)



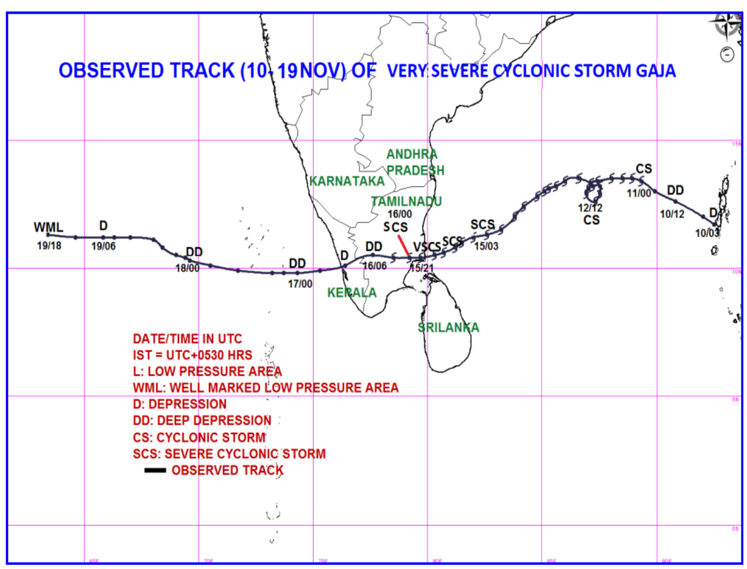


Fig-2: Cyclone Category (*Source: IMD*) **Fig-3:** Observed track of Cyclone Gaja (*Source: IMD)*

Table -1: List of Sentinel-1 scenes

Scene	Date	Description	Purpose in the study
S1A_IW_GRDH_1SDV_20181108T003213_20181108T003238_024489_02AF7A_4E6C	12/11/2018	Pre Cyclone	To investigate the waterlog areas during non hazard period
S1A_IW_GRDH_1SDV_20181108T003238_20181108T003303_024489_02AF7A_AAA8	12/11/2018	Pre Cyclone	
S1A_IW_GRDH_1SDV_20180217T003204_20180217T003229_020639_023578_3763	16/11/2018	Cyclone	To investigate the waterlog areas during cyclone period
S1A_IW_GRDH_1SDV_20180217T003229_20180217T003254_020639_023578_33B2	16/11/2018	Cyclone	
S1A_IW_GRDH_1SDV_20181120T003213_20181120T003238_024664_02B5ED_EB05	20/11/2018	Immediately after Cyclone	To investigate the waterlog areas immediately after hazard period
S1A_IW_GRDH_1SDV_20181120T003238_20181120T003303_024664_02B5ED_3DB5	20/11/2018	Immediately after Cyclone	
S1A_IW_GRDH_1SDV_20190224T003210_20190224T003235_026064_02E80B_2695	24/02/2019	Post Cyclone	To assess the duration of water inundation and damage assessment due to prolonged water stagnation
S1A_IW_GRDH_1SDV_20190224T003235_20190224T003300_026064_02E80B_D33C	24/02/2019	Post Cyclone	

4. METHODOLOGY

The approach of the study includes processing of SAR images for waterlog areas extraction and temporal MSS data for feature extraction and their damage assessments. Spatial information derived by two remote sensing data was further integrated to assess the duration of water inundation and their impacts as shown in Fig 4.

4.1 SAR data processing and Creating water mask (water logged area created using binarization)

Image pre-processing was done to each Sentinel-1 IW dataset in order to reduce orbital errors, speckle noise, and geometric distortion. Pre-processing of the images were carried out in SNAP (Sentinel Application Platform) software. The raw Sentinel data were subset to extract the study area. The extracted images were calibrated, by which the pixel values can be directly related to the radar backscatter. Calibrated SAR images are essential for quantitative use of the SAR data.

SAR images have inherent salt and pepper like texturing called speckles which degrade the quality of the image and make interpretation of features more difficult. To reduce the speckle effect and to smoothen the image, filtering technique was performed with the help of speckle filter. To remove the distortions in the SAR images, due to topographical variations of a scene and tilt of the satellite sensor, terrain correction was done. The images were then projected to UTM projection with WGS84 datum.

Smooth open water surfaces are characterized by a low SAR backscatter (appears white in color in processed image) and can be well distinguished from non-water areas which show a higher SAR backscatter appearing black in the processed image.To separate water from non-water area, threshold can be selected for each image. For this, the histogram of the filtered backscatter coefficient was analysed. Low values of the backscatter correspond to water and high values correspond to non-water class. The low and high threshold values considered in the study were 0 and 1 respectively by which the water logged areas and non-water areas were separated in the SNAP software using binarization method for different time period mentioned earlier. The resultant raster output was exported to GIS software for further quantitative and spatial analysis.

4.2 Extraction of temporal land features from MSS data

The raw LISS IV MSS images of different period were subset to the study area and georeferenced using Ground Control Points (GCP) in UTM and WGS84 datum. The existing land features of the study area were mapped from the temporal georeferenced images using standard interpretation keys such as size, shape, tone and texture in image processing software and exported to GIS for further analysis.

By the above mentioned approaches images of 12th Nov and 20th November of 2018 and 24th February of 2019 were considered for extraction of land features along with new water stagnations due to cyclone.

It was noteworthy to indicate that multispectral images such as LISS IV were obtained from sensors operated in visible optical wavelength and borne the constraint of capturing data during heavy cloud cover unlike SAR images which penetrate cloud cover to capture spatial data under all weather conditions. Thus such images were not suitable for study during hazards. However images before and after the hazard which were relatively cloud free were considered to extract the land features to overlay with the inundated areas during the hazard.

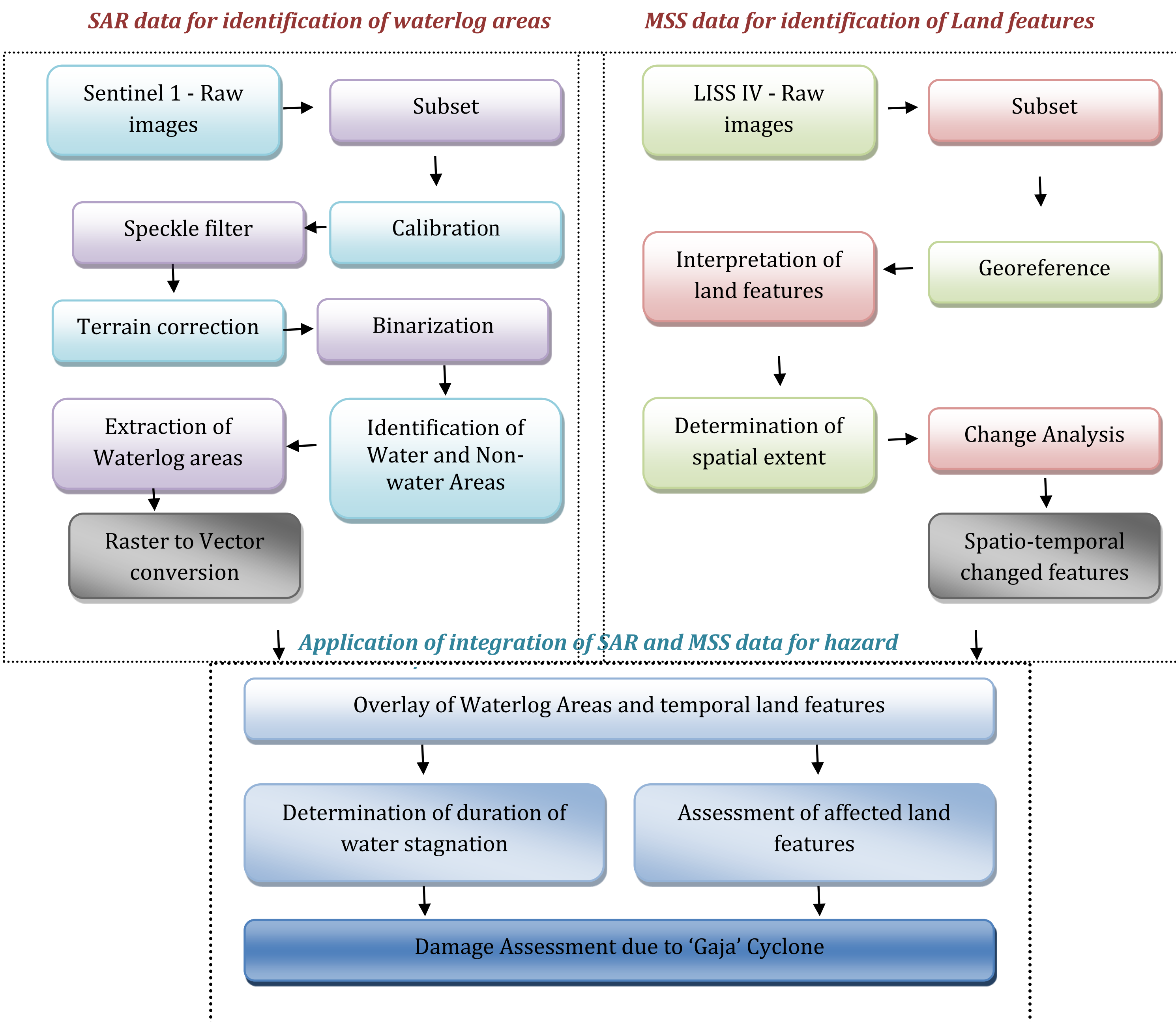


Fig-4: Approach of the study

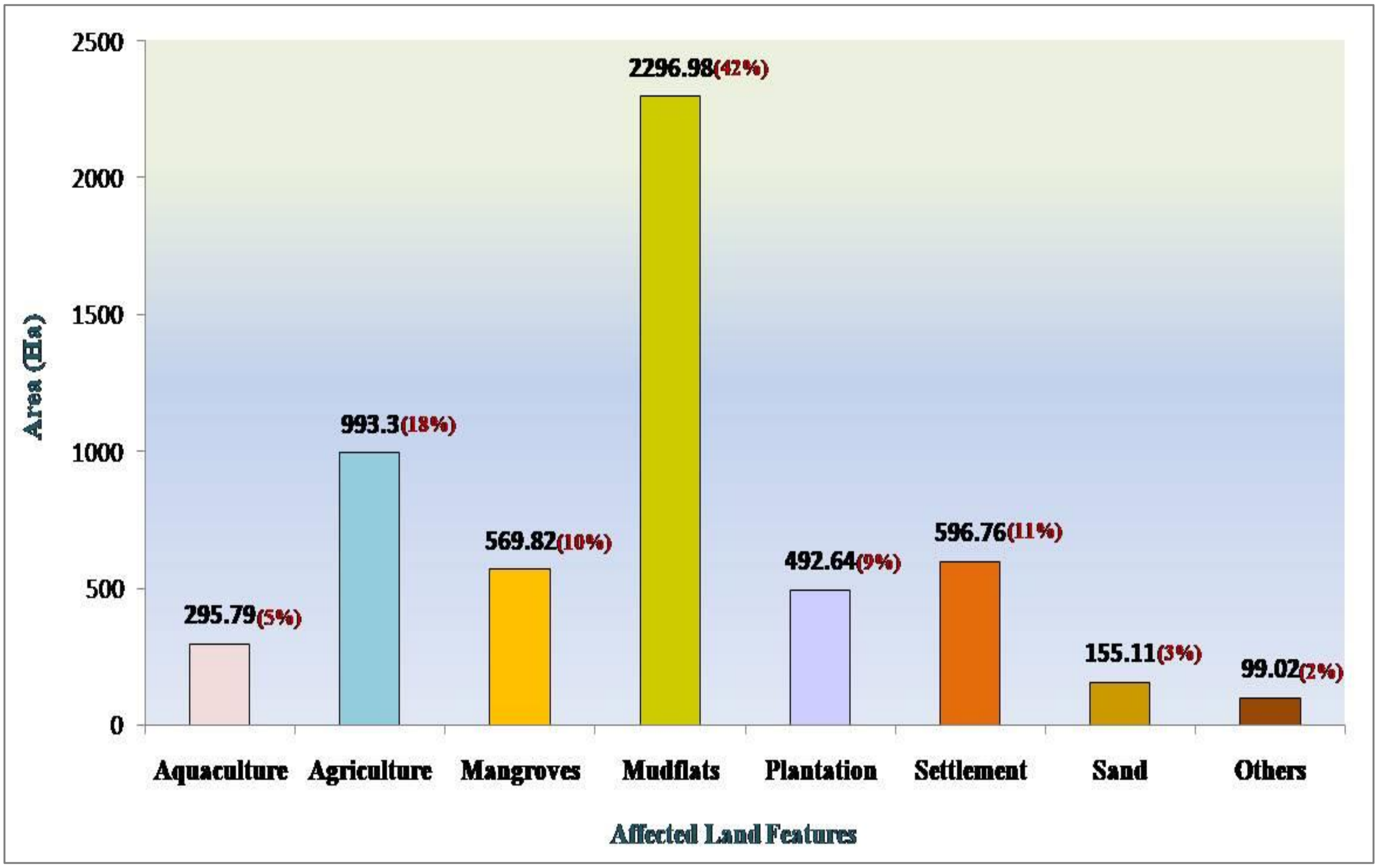


Fig-11: Spatial extent of affected land features due to Gaja C

6. CONCLUSION

The study aimed to demonstrate the application of Sentinel-1A SAR data in identification and mapping of water stagnant areas. To demonstrate the application of such studies a real-time extreme event, the very severe 'Gaja' tropical cyclone occurred in the Nagapattinam district was considered. Owing to the capability of capturing spatial information on cloudy conditions, SAR data of different period such as before, after and at the time of tropical cyclone in the study area were used. With advance techniques of remote sensing waterlogged areas and non-water areas were identified using binarization method in SNAP platform. Further in the study, water areas were extracted for estimation of water inundation and its impact analysis. The water areas were further classified as waterlog areas during normal and cyclone condition and impact analysis were based on the waterlog areas due to cyclone. The study indicated waterlog of about 5532 hectares due to cyclone calamity. The study also attempted to identify the features affected by water stagnation and its duration by assessing temporal MSS images before and after the cyclone in GIS (Geographical Information Science). The outcome of the study indicated that agriculture, plantation, aquaculture farms, saltpans, water bodies and settlement areas were the most affected land features due to cyclone besides loss of coastal mangroves. The spatial information revealed by the study was particularly useful to government and government organizations for rescue operations in such calamity conditions. Apart from the rescue operations, identification of waterlogged areas using SAR data can be used to assess the damage of agricultural areas and change in soil pH due to prolonged water stagnation as this would lead to increased soil salinity and decreased crop productivity. Frequent cyclone prone areas would particularly be benefitted with similar kind of studies to combat and mitigate hazardous situations for better rescue, damage assessment, management and preparedness.

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REFERENCES

1. Alsdorf D.E., Rodriguez E. & Lettenmaier D.P (2007) Measuring surface water from space. Rev Geophys, 45(2).
2. Brivio P.A., Colombo R., Maggi M. & Tomasoni.R (2002) Integration of remote sensing data and GIS for accurate mapping of flooded areas. Int J Remote Sens, 23(3):429– 441.
3. Chang Liu (2016) Analysis of Sentinel-1 SAR data for mapping standing water in the Twente region. A Thesis, University of Twente, Netherlands.
4. Clement.M.A , C.G. Kilsby and P. Moore (2018) Multi-temporal synthetic aperture radar flood mapping using change detection. Journal of Flood Risk Management 11:152–168.
5. Gan T.Y., Zunic F., Kuo C.-C. & Strobi.T (2012) Flood mapping of Danube River at Romania using single and multi-date ERS2-SAR images. Int J Appl Earth Obs Geoinf, 18: 69– 81.
6. Giustarini L., Hostache R., Matgen P. & Schumann G.J.P. (2013) A change detection approach to flood mapping in urban areas using TerraSAR-X. IEEE Trans Geosci Remote Sens , 51(4):2417– 2430.
7. Horritt M.S., Mason D.C. & Luckman A.J. (2001) Flood boundary delineation from synthetic aperture radar imagery using a statistical active contour model. Int J Remote Sens , 22 (13): 2489– 2507.
8. Hostache.R, Matgen,P and Wagner.W (2012) Change detection approaches for flood extent mapping: How to select most adequate reference image from online archives? International Journal of Applied Earth Observation and Geoinformation, 19(1):205-213.
9. Jung H.C., Hamski J., Durand M., Alsdorf D., Hossain F., Lee H., Hossain A., Hasan K., Khan A.S. & Hoque A. (2010) Characterization of complex fluvial systems using remote sensing of spatial and temporal water level variations in the Amazon, Congo, and Brahmaputra Rivers. Earth Surf Process Land, 35(3): 294– 304.
10. National Commission on Agriculture. (1976). Report of the National Commission on Agriculture. Part V, IX, Abridged Report. Ministry of Agriculture and Irrigation, New Delhi.
11. Pandey.A.C, Suraj Kumar Singh, M. S. Nathawat (2010) Waterlogging and flood hazards vulnerability and risk assessment in Indo Gangetic plain. Natural Hazards, 55:273-289.
12. Schlaffer S., Matgen P., Hollaus M. & Wagner W. (2015) Flood detection from multi-temporal SAR data using harmonic analysis and change detection. Int J Appl Earth Obs Geoinf, 38: 15– 24.

13. Schumann.G, Di Baldassarre.G and Bates.P.D (2009) The utility of spaceborne radar to render flood inundation maps based on multialgorithm ensembles. Transactions on Geoscience and Remote Sensing, 47(8):2801-2807.
14. Suraj Kumar Singh (2017) Evaluation of flood and waterlogging dynamics in Indo-Gangetic plain using Geospatial technique: A Review. International Journal of Science and Engineering, 2(3):1-7.
15. Suvrat Kaushik, Pankaj R. Dhote, Praveen K. Thakur (2019) Identification of waterlogged areas in Rohtak district using satellite imageries. Asian Conference on Remote Sensing.

ANNEXURE

Annex I

Rainfall recorded during Gaja Cyclone in the study area

Under the influence of Gaja cyclone on 16th November 2018, rainfall occurred at most places with heavy falls in few places and very heavy fall at isolated places in and around Nagappattinam distict. The recorded annual rainfall of Nagapattinam district for the year 2018 indicated an increased rainfall in November as high as 475 mm as shown in Fig.13.

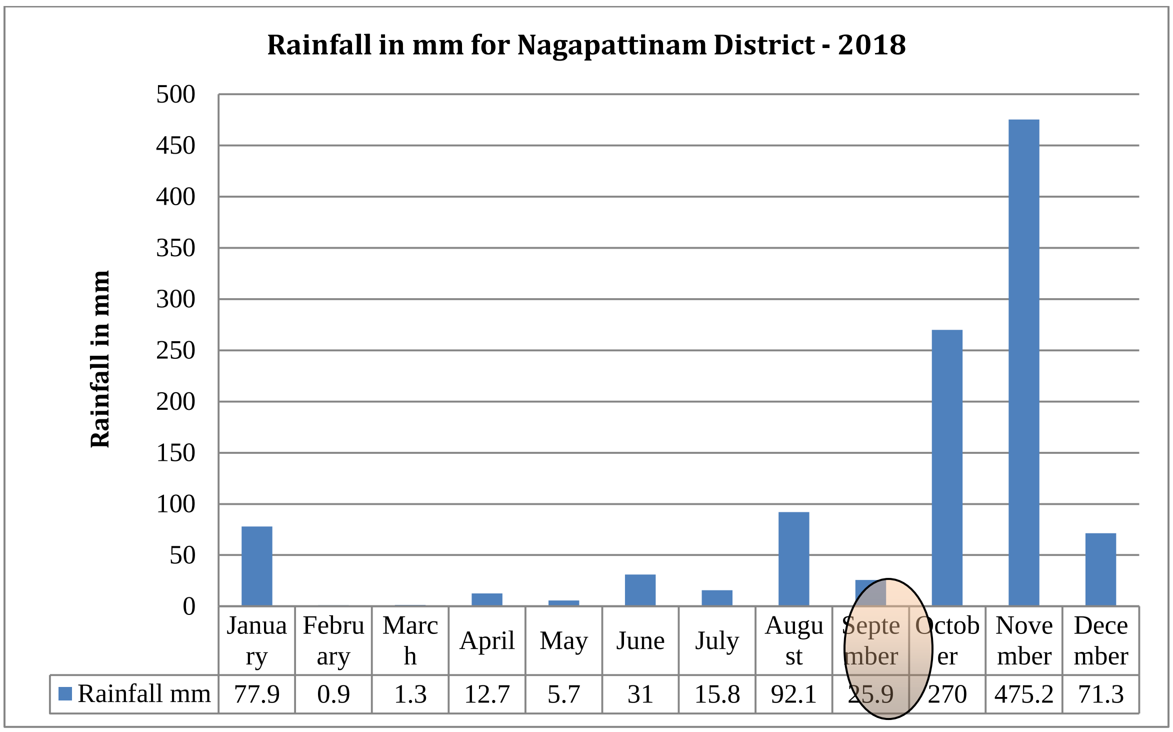

Fig.13 Month wise Rainfall Distribution for the year 2018*(Source: IMD)*

Annex II

The dynamics of different land features in the study area

Table 3: Temporal land utilisation of the study area

S.No	Feature Name	Spatial Area (Ha)		
		12th Nov 2018	20th Nov 2018	24th Feb 2019
1	Mangroves	1521	1309	1259
2	Agricultural Land	30721	24528	17652
3	Aquaculture	2829	1706	1910
4	Saltpan	3804	2006	2611
5	Canal	575	1180	978
6	Industrial Area	25	20	21
7	Tanks/Ponds	496	1812	767
8	River	952	2059	1162
9	Lagoon	660	2328	542
10	Barren/Salt affected land	572	12173	18921
11	Scrub Land	8028	4918	7568
12	Mudflat	8061	5176	7176
13	Plantation	8825	7211	6061
14	Reserve Forest	1318	911	838
15	Sandy Area	170	136	116
16	Sandy Beach	327	306	251
17	Settlement with Vegetation	9095	7991	8703
18	Water Logged area	4193	6402	5636
	Total	**82172**	**82172**	**82172**

It was noted from the study that most of the affected land features were converted to either barren lands or scrub lands.