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Post-disaster assessment of impact of cyclone *Lehar* in South Andaman Island

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Disasters are the events which devastate human lives, properties and natural ecosystems; cyclones are frequent events in tropical countries which have adverse impacts on coastal areas. The present study evaluates the impact of cyclone *Lehar* post-disaster in the South Andaman Island using geographic information system (GIS) and remote sensing techniques. Cyclone *Lehar* originated in the Andaman Sea and had a major impact on the South Andaman Island. Digital elevation model was used to create elevation and slope maps of the study area. These maps were used to study the impacts of floods, landslides, storm surges and runoff. Land-use and land-cover features were mapped and overlaid with this model for preparing the vulnerability map for various outcomes of the cyclone. Preliminary impact assessments were made in these identified vulnerable areas and also throughout the study area. Finally the results were interpreted with vulnerability map prepared using the GIS technique which shows that most of the affected areas are correlated with the vulnerability map. Cyclone *Lehar* had adverse impacts on natural ecosystems such as forests, mangroves and sandy beaches. It also damaged man-made features such as settlements, infrastructure, agricultural fields and plantations. This study proves spatial technologies are the indispensible tools for post-disaster planning and impact assessment.

Keywords: Cyclones, impact assessment, post-disaster planning, spatial technologies.

THE Earth is experiencing frequent natural disasters, and their incidence and intensity seems to be increasing in recent years, particularly cyclones and floods which often cause significant loss of life, large-scale socio-economic impacts and environmental damage[1,2]. Two cyclones originated in the Andaman Sea during October–November 2013 and devastated bay islands and the east coast of India. Disaster-causing factors of tropical cyclones including those related to strong wind, rainstorms, floods and storm surges are the prerequisites and driving forces of tropical cyclones[2]. In addition, global warming intensifies the cyclone activity leading to severe loss and damages[3,4] to public properties and the environment. Risk can be measured either as loss of life, injuries, loss of property, livelihoods or other economic activities or

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environmental damages resulting from natural hazards and vulnerable conditions of the area[5–7].

Development of satellites and spatial technologies in late nineties has resulted in significant improvement in tropical cyclones studies[8]. Recent advantages in spatial technologies have been used for damage assessment in the case of disasters like cyclones and floods[9]. Remote sensing and geographic information system (GIS) can accurately support better response planning the affected areas such as determining evacuation routes or locating vulnerable infrastructure and vital lifelines, etc.[10]. However, there are some limitations in this technique for real-time disaster planning which include the scale of spatial data and its suitability for regional scale[11]. So the real-time impact assessment of cyclone *Lehar* was made.

The deep depression originated over South Andaman Sea and its neighbourhood about 300 km south-southeast of Port Blair, which moved northwestward and intensified into a cyclonic storm called *Lehar*. The cyclone crossed Andaman & Nicobar Islands (ANI) between Hut Bay and Long Island, close to Port Blair around early morning of 25 November 2013. Then it emerged into southeast Bay of Bengal, gradually slowed down and moved towards northwest of Andhra Pradesh coast. The track of the cyclone over South Andaman Island was mapped using the cyclone data obtained from India Metrological Department[12] (Figure 1).

During the cyclone there was heavy to very heavy rainfall of around 25 cm at most places of the South Andaman. Whereas in the sea condition severe storm surge of about 1–1.5 m height and inundated the low-lying areas of ANI. The speed of gale winds was 90–100 km/h, which damaged the huts, thatched roofs, etc.

The southern part of South Andaman was chosen as the study area to identify various impacts caused by the cyclone *Lehar*. South Andaman Island has undulated topography with small terrain tracts and coastal low-lying land. Climate is tropical hot humid with average temperature ranging from 18°C to 36°C. ANI receives rainfall for eight months in a year with average rainfall ranging from 3000 to 3500 mm (ref. 13). The south Andaman Island constitutes one of the hotspots of biodiversity with a variety of ecosystems such as tropical forests, wetlands, mangroves, coral reefs and sandy beaches. Major economic activity is based on coastal ecosystem services which attract tourists from India and abroad, with the average tourist visit of about 120,000/year this is increasing every year[14]. Another important economic sector of the study area is fishing. Population of the South Andaman Island is 237,586 according to the 2011 Census report[14], particularly the coastal areas having dense population due to their economic importance[15].

IRS R2 (Indian Remote Sensing Satellite-Resource-sat 2, 1 March 2013) satellite image with spatial resolution of 5.6 m was used for preparing the land-use and land-cover map. Survey of India (SOI) toposheet (1979) with scale range 1 : 50,000 was used to prepare contour maps for the digital elevation models (DEM). Village boundary map was collected from the Public Works Department. Software packages such as ERDAS IMAGINE 9.1 and ARCGIS 10 were used for image processing, digitizing mapping and analysis purposes.

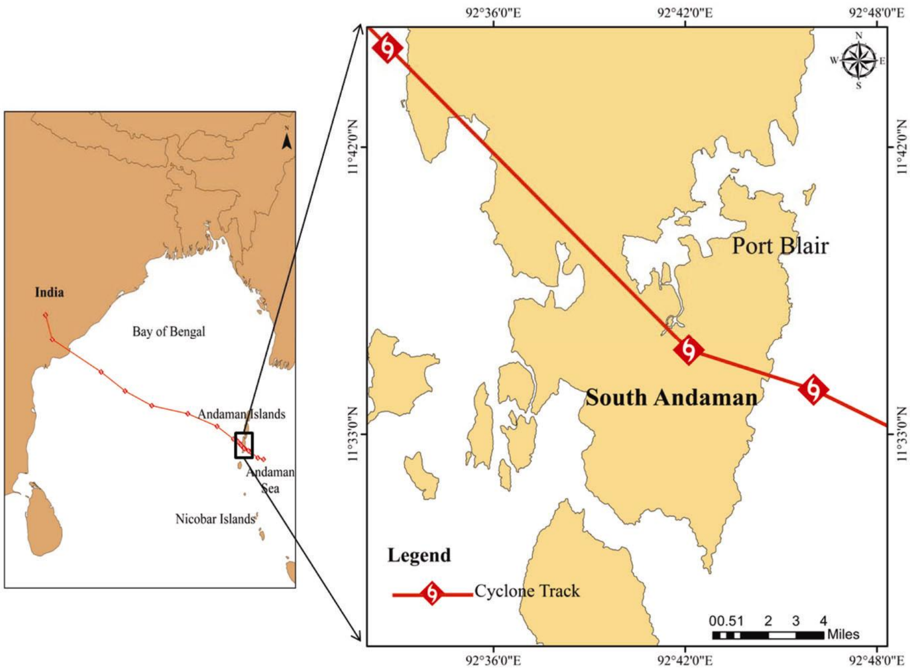

Figure 1. Map of the study area in South Andaman showing the path of cyclone *Lehar*.

To estimate the impacts of cyclone *Lehar* in the study area, different types of parameters from spatial data were taken as factors to identify the vulnerable areas for a preliminary survey. The flow chart of the complete methodology adopted for this study is shown in Figure 2. Land-use and land-cover map was prepared from the orthorectified IRS R2 satellite image. The topographic contours from the SOI toposheet were used to generate the triangulate irregular network (TIN). The raster DEM map was prepared from the TIN data to find the low-lying areas, vulnerable slopes and coastal lowlands. DEM models could be useful in delineating inundation area extent and flood depths[16]. The DEM maps were overlaid with land-use and village maps to identify the vulnerable areas and vulnerable population. The real-time impact assessment was made with the help of the above maps and the accuracy was verified by detailed field survey.

The forests of the South Andaman Island are one of richest in the country in terms of biodiversity. Champion and Seth[17] have classified these forests into ten types varying from tropical rainforest to Andaman deciduous forest. Mangrove forest is the most productive ecosystem which contributes 10% of the total forest of the island. Coral reefs of the island are among the most spectacular and extensive in the world. Currently, they are not only significant for the Indian Ocean region but are also globally significant[18,19]. There are many small pockets of most beautiful sandy beaches are present in the study area which attracts national and international tourists.

Urban settlements with houses and built-up structures are present in and around the capital city Port Blair (Figure 3). Rural settlements of the South Andaman Island include many small villages whose agricultural activities are practised, particularly in the flat lands and low-lying areas growing paddy, pulses and oil seeds. Plantation crops such as coconut, areca nut and cashew nut are also grown in hilly tracts and coastal zones[20].

Based on the vulnerability map prepared using geospatial technique (Figure 4), the preliminary survey was planned to assess the various impacts caused by different cyclonic factors. The survey was carried out on almost the entire part of the study area for damage assessment of settlement, plantation, agriculture, infrastructure and natural resources such as forests, mangroves and sandy beaches. The damages were estimated based on the cyclonic factors such as floods, run-off, landslides and storm surges affecting the land-use and land-cover features. Settlement damages were assessed by breakage, lifted and missed thatched roofs, wall damage and impact of landslides on the basement of house. Infrastructure damages were assessed in numbers, which includes bridge damage, inclined transformers and electric poles and seawall damage. Impacts on agriculture and plantation were also assessed based on uplifted plants and flooding impacts on

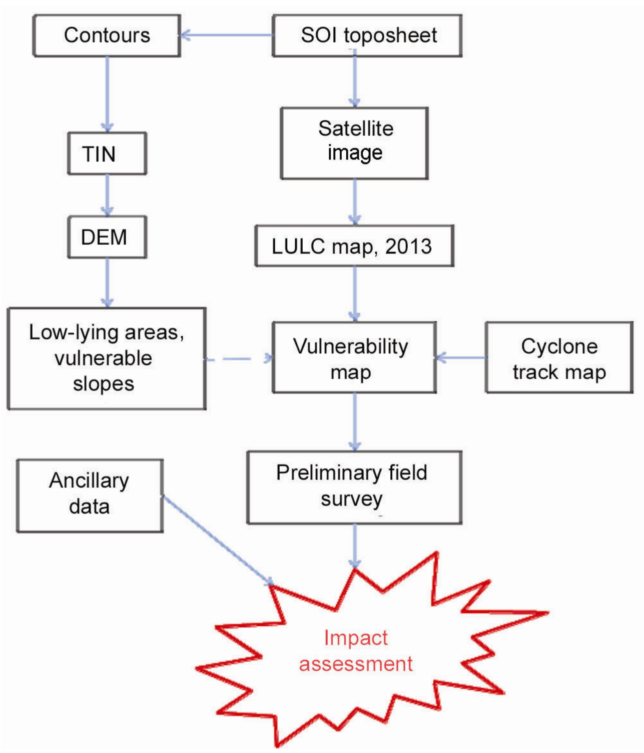

Figure 2. Flow chart of methodology adopted for the study.

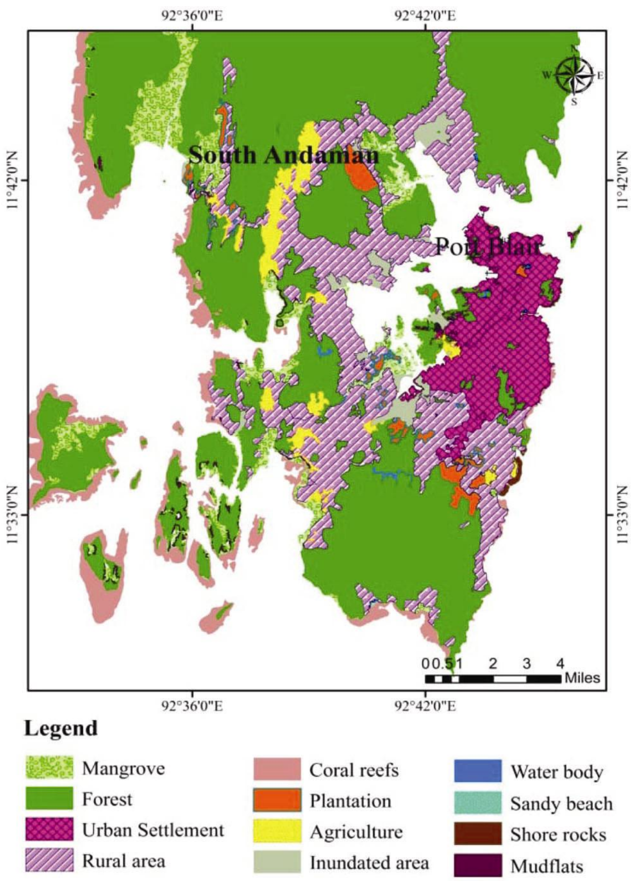

Figure 3. Land-use/land-cover map of the study area.

Table 1. Preliminary damage assessment for cyclone *Lehar*

Disaster	Damaged houses*	Infrastructures**	Plantations# (ha)	Agriculture# (ha)	Forest# (ha)	Sandy beaches# (ha)
Flood inundation	12	117	15	6	20	–
Escaping run-off	17	26	3	5	12	3
Landslide	15	19	11	–	8.5	–
Gale winds	36	9	16	3	6	–
Storm surge	35	15	9	–	7	2.3
Total	115	186	54	14	53.5	5.3

*Includes storm-affected thatched roofs, flood-damaged walls and landslide impacts. **Includes bridges, sea walls, electric transmissions and transformers. #Approximately estimated based on GPS tracks.

crops. Preliminary survey of forests includes broken branches of trees and uprooted trees. In case of mangroves the run-off impacts and debris deposition areas were surveyed. Erosion in sandy beaches by run-off and storm surge was also estimated based on GPS tracks and manual assessment in the field.

During cyclone severe winds (120 km/h) damaged the thatched roofs and huts present near the open coast and hilly areas. The flood caused inundation and damage to the walls of houses in the low-lying areas of Junglighat and Carbyn's cove. Run-off due to heavy rainfall along the slopes eroded the soils and debris which damaged the basement of the houses. Extreme run-off in the slope of marine hill caused landslide which disturbed the normal life of people for two days; people were shifted to the nearby community hall. The expected storm surge was 0.45 m from the normal level[12], but the real-time impact was identified as 1.75 m which affected the land use and settlements in the coastal areas. In Burmanala also, settlements near the coast were damaged. The unexpected increase of flood water due to storm surge in the low-lying coastal areas led to stagnation of flood water in the settlements for more than half a day. Totally 115 houses were damaged by this cyclone in the study area.

Power supply was disrupted because of severe storm winds and caused damage to the electric poles in Sippighat, Garacharma and Mangulton. At Marine hill and Nayagoan, the uprooted trees caused severe damage to electric poles and disturbed power supply. In Carbyn's minor landslide disturbed the electric lines. Even the Government hospital in Port Blair did not have power supply for more than a day. Severe flood and debris flow caused damage to the bridge in marine hill and affected the nearby settlements. Bridges in Sippighat area were also affected by the flood causing inconvenience to transport. The total infrastructure damage by flood was 117 including four bridges in necessary roadways (Table 1).

Agricultural activities practised in Chouldhari, which is a flat lowland situated near the coastal area were affected by cyclonic storm. In Tsunabad area the agricultural and pasture lands were affected by run-off from the catchment areas. Patches of land practising agriculture activities in most of the places were also affected by flood. The damages were surveyed using GPS tracks and it was estimated that 14 ha was affected.

Most of the plantations in the highly elevated slopes, particularly areca nut and coconut plantations were affected by gale winds and flood run-off. Most of the trees were uprooted and damaged along the track of the cyclone. Some of the coastal plantations such as coconut and cashew nut were also damaged due to storm surge. Banana and sugarcane plantations in the inland area were affected as they were unable to withstand to gale winds. Approximately 54 ha of plantations was affected, including uprooted and broken trees.

Uprooted trees and broken branches were identified in most places of the South Andaman, including Sippighat, Mangulton, Tsunabad and Burmanala forest covers around 53.5 ha (Figure 5 *a*). With different types of forest present in the South Andaman, some of the trees shed their leaves due to severe winds. Also, severe flooding led to significant damages to mangroves – sediment removal and debris deposition in coastal wetlands and mangroves (Figure 5 *b*). Storm surge also damaged the fringing mangroves present in the shoreline of Carbyn's cove.

Most of the sandy beaches were severely eroded by extreme run-off and storm surge. Approximately 1–1.3 m of sediments was washed out in the beaches such as Carbyn's cove, Wandoor and Chidyatapu. These cover 5.3 ha in total beaches present in the study area, resulting in the loss of tourism. These beach sediments logging over the coral reef were noticed during field survey. This may leads to loss of tourism, which is the important economic source for local people and the Government.

The land-use map shows that coastal areas have dense population, developed structures and exposed natural resources in the South Andaman Island. The cyclone caused enormous damage to man-made structures such as houses, roads, tourism structures and other recreations in the coastal areas. It had a major impact on natural ecosystems such as forests, mangroves, sandy beaches and coral reefs. Damage to property caused by gales was extensive such as damage to huts and thatched roofs, uprooting of trees and breaking of branches, damage to electric poles, etc. largely in the cyclone path. These were

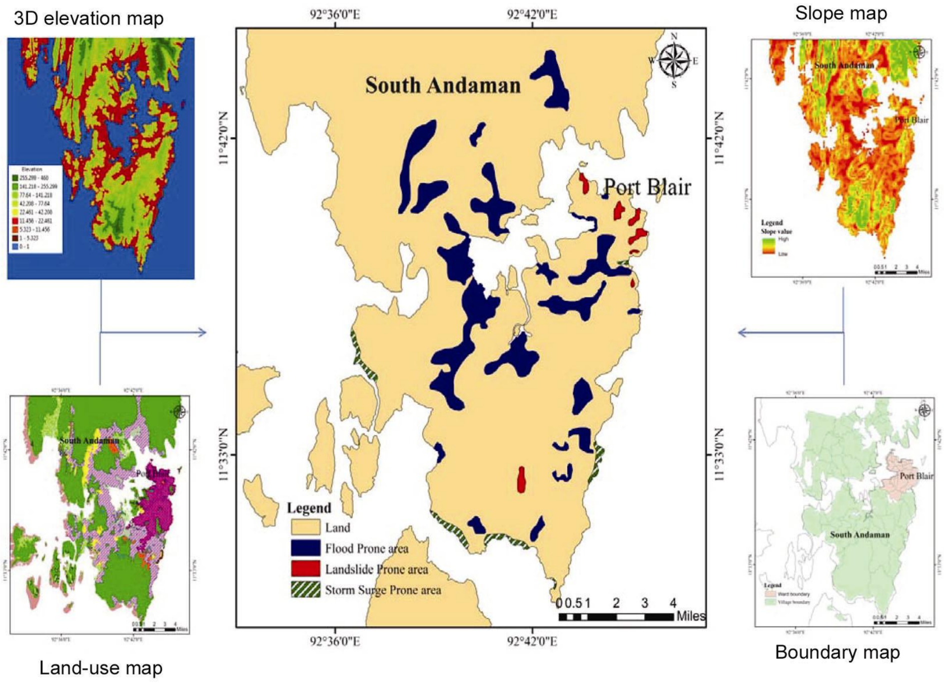

Figure 4. Vulnerability map for disaster causing factors of cyclone prepared using geospatial techniques for the field survey planning.

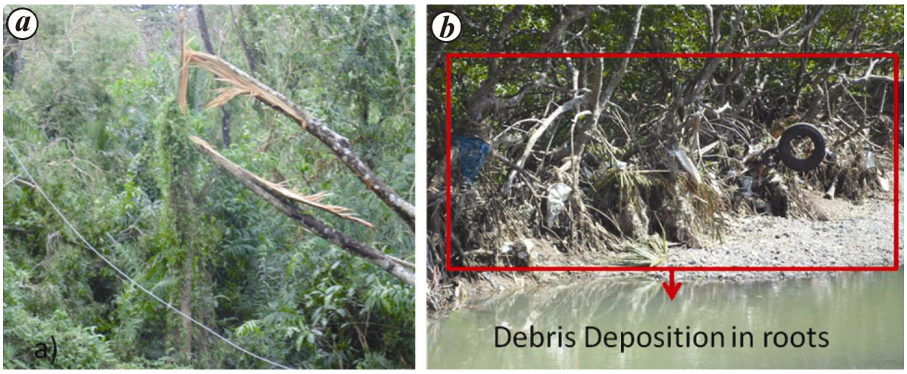

Figure 5. ***a***, Trees broken due to gale winds near Mangulton. ***b***, Debris deposition in the mangrove stilt roots.

interpreted with the vulnerability map which shows that 76% of the damages was noticed in the vulnerable zones. Most of the vulnerable areas correlated with the high impact areas. Damages caused by the gales were noticed randomly throughout the study area.

In this study real-time impact assessment of cyclone *Lehar* in the South Andaman Island was made mainly using the existing vulnerable maps. It was identified that land-use and land-cover features in flat lands, low-lying coastal areas and high slopes were affected by the cyclone. The experience from the present cyclone shows that a proper evacuation route map, shelter notification, emergency kits and power back-up should be maintained in a sustainable manner. This study indicates needs of the detailed impact assessment in the village and community level for identifying the socio-economic losses, which are useful for better rehabilitation and mitigation activities. Damages to natural resources are enormous when compared to man-made structures. Particularly, coastal ecosystems of this island were drastically affected by this disaster. It is important to assess the cyclonic impacts on natural ecosystem for sustainable natural resource management, which is an eminent economic source and natural protection for the people of ANI. A sustainable land-use plan with suitable risk reduction structures for this multi-hazard environment is needed for a better disaster-free future for this island.

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Application of fast Fourier transform in fluvial dynamics in the upper Brahmaputra valley, Assam

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Large tropical rivers such as the Brahmaputra flowing through tectonically active areas show highly variable bankline migration for the channel belt as a whole, as well as intra-bank, over different time windows due to different but non-uniform forcings. Fast Fourier transform (FFT) can be applied to identify frequency (cycles per unit length) content of bankline migration, to classify the wavelengths of different forcings and subsequently to compare the relative influence of different forcings for the trend analysis of bankline shift and width variation. This helps expand the interpretative scope of dynamics of river systems and plan mitigation strategies.

Keywords: Bankline migration, fast Fourier transform, fluvial dynamics, forcings.

THE upper reaches of the Brahmaputra River, from the 1915 confluence of three great rivers, the Lohit, the Dibang and the Siang at Kobo, up to the Mikir hills SW of the Brahmaputra valley in Assam have witnessed some of the onset spectacular riverscape changes during the last century[1–6]. We have studied the stretch sandwiched between the NE–SW trending Himalayan Frontal Thrust (HFT) and the Naga Patkai Thrust (NPT) belt covering approximately 240 × 80 sq. km area (Figure 1). The study area was subdivided into three units: a newly formed river island (Dibru–Saikhoa Reserve Forest or 'new Majuli') bearing channel belt in the upstream side (unit 1), the middle connecting link (unit 2) and the 'old Majuli' bearing belt in the downstream side (unit 3).

Our earlier works[7,8] have documented at least five major changes of considerable geomorphological significance in the Brahmaputra River channel during the period 1915–2005. First, the average width of the channel belt changed from 9.74 km in 1915 to 11.65 km in 1975 (i.e. 19.6% increase) and then further to 14.03 km in 2005 (44% increase compared to 1915). Secondly, during the same period, the largest colonized river island, the Majuli, eroded alarmingly and its area changed from 797.87 sq. km in 1915 to 640.5 sq. km in 1975 and then to 508.2 sq. km in 2005 – this means a reduction of 18.7% to 35.5% in terms of area compared to 1915. Thirdly, the Dibru–Saikhoa Reserve Forest, a hotspot of biodiversity,

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