SHORT NOTE

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ASSESSMENT OF *TSUNAMI* IMPACT IN SOUTH ANDAMAN USING REMOTE SENSING AND GIS

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It was a tragic memory to recall December 26, 2004 when an earthquake of magnitude 9.0 on richter scale struck off the west coast of Sumatra in the Indonesian archipelago at 6:29 hrs IST. This resulted in upliftment of seafloor, which created *tsunami*, killing thousands of people and damaging properties worth millions of dollars, across different countries.

Tsunami is a Japanese word which translates as 'harbor wave', now used internationally, refers to a series of waves traveling across the ocean with extremely long wavelengths at an average speed of 800 km/hour in the open ocean. The near shore bathymetry significantly increases the wave height with the approach of tsunami resulting in inundation of low lying areas along the coast and mass destruction (Navalgund, 2005).

In India, the states of Tamil Nadu, Andhra Pradesh and the Union territories of Andaman and Nicobar Islands and Pondicherry were severely affected by *tsunami*. In Andaman and Nicobar Islands, the impact was felt on the Infrastructure, Settlements, Coastal geomorphology and Land use/ land cover. Soils are one of the vital natural resources and maintaining the quality of soil is a key issue in ensuring agricultural sustainability and food security. The soils of the south Andaman Islands have developed under the dominant influence of vegetation and climate over diverse parental materials. The uplands and deforested areas are intensively eroded (Ganeshamurthy, 2002). The seawater intrusion into the agricultural land has resulted in increased pressure on the already constrained land resources of these Islands. Among the Andaman group of islands, south Andaman is the major inhabited island and has larger area under cultivation experienced severe damage. Considering the importance of agriculture and severity of damage to cultivated lands, t*sunami* impact analysis of soils and agriculture of south Andaman Islands was carried out to identify and delineate the *tsunami* affected areas (revenue areas only); determine the changes in soil characteristics like pH, EC, ESP and SAR as well as land quality indicative parameters; and to assess the severity of damage and prioritization of the areas to develop management options.

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Delineation of *tsunami* affected areas, data collection and assessment of field damage by ground based survey in south Andaman is both challenging and time consuming due to difficult terrain and inaccessibility of several areas. Remote sensing and geographical information system (GIS) has the potential to address these challenges. However, due to cloud cover over south Andaman Islands, unavailability of timely remote sensing data, interpolation errors and to achieve maximum accuracy in estimation, ground verification was necessary. Hence, remote sensing and Geographical Information System (GIS) and ground based data was used to assess the impact of *tsunami* on south Andaman with reference to agriculture and soils.

Selection of proper indicator is the prime task to identify and delineate the affected areas. The visible indicators are flooding and change in soil moisture content. Satellite remote sensing data have been widely used to delineate the water features on land (Blasco and Bellan, 1992; Nagarajan *et al.*, 1993; Sharma *et al.*, 1996). Detection and delineation of spatial extent of water feature can be enhanced using Normalised Difference Water Index (NDWI) derived from satellite remote sensing data (McFeeters, 1996)

$$NDWI = (Green - NIR) / Green + NIR) \qquad (1)$$

Where, Green is a band that encompasses reflected green light and NIR represents reflected near infrared radiation.

While using equation (1) for processing a multispectral satellite image, water features have positive values while soil and vegetation features have zero or negative values owing to their higher reflectance of NIR than Green band which can be easily removed using image processing software (Chatterjee *et al.*, 2003). Further, encouraging results have been obtained in delineating the water logged areas with either standing water or a thin film of water at the surface or the land with wet surface using Landsat (MSS and TM) and IRS data (Dwivedi *et al.*, 1999; Ray *et al.*, 2002; Goyal *et al.*, 2005).

In the present study, NDWI of pre and post *tsunami* remote sensing data was used to delineate waterlogged areas. The NDWI image was used as an input with SOI toposheet to carry out ground verification survey and suitable corrections were made to get the final affected areas. Visual interpretation of remote sensing data of post *tsunami* was also used as an input while delineating the affected areas.

Land use/land cover map (Level-I) of south Andaman was prepared using IRS-1D data following the National Remote Sensing Agency (NRSA) classification scheme and method (Rao, 1990). Soil series map was also prepared using National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) soil map of south Andaman with lateral inputs from remote sensing data. The affected area map was crossed with agriculture and soil map to get their respective affected areas. These maps were used to locate the sampling sites in the affected areas and stratified random samples from soil surface (0-30 cm) were collected both from the *tsunami* affected and unaffected areas. The soil samples were air dried and passed through 2 mm sieve and analysed for pH (soil and water ratio 1:2), Electrical Conductivity (ECe) (Saturated extract), Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR) following standard procedures (Jackson, 1973).

Analytical results of soils from the affected areas were interpolated to prepare thematic layers of pH, EC, ESP and SAR using geographical information system software (Arc GIS version 9.0). Results of unaffected areas were compared with the affected areas in order to understand the changes in soil physico-chemical properties as a result of *tsunami*. Other thematic layers like flood duration, trash and debris, soil texture were also prepared following the procedure described in Fig. 1.

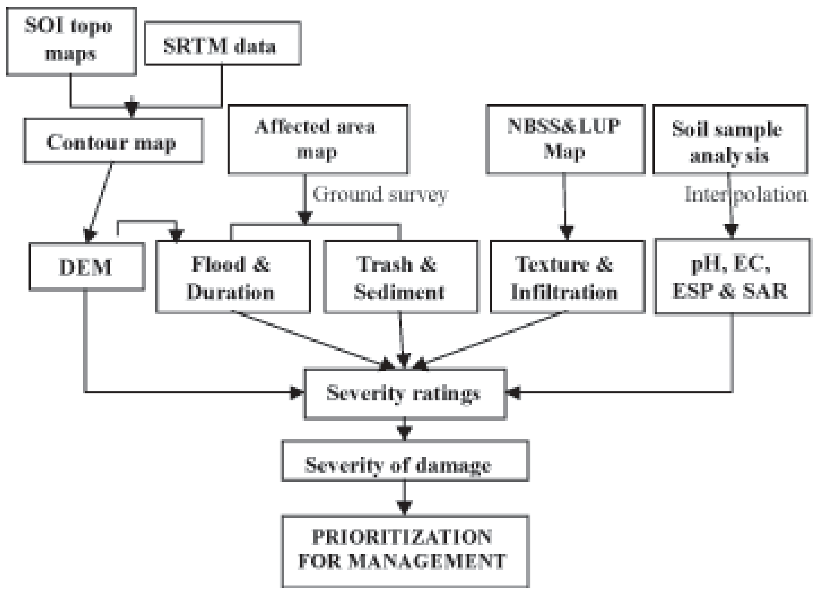

Fig. 1. Methodology to prepare various thematic layers and severity of damage map

The parameters selected to assess the severity of damage were classified as low, medium, high and very high to account for its severity and spatial variability. The values or range of values used to classify the thematic layers into various severity classes were decided by following modified Food and Agricultural Organisation methodology (2005). The estimated values and their respective damage ratings of selected parameters are given in Table 1). The relative importance of selected parameters on various soil physico-chemical properties were considered and was given a weightage on a scale ranging from 1 to 4 (low to high) (Table 2).

Table 1: Ratings for the selected parameters used to assess the severity of damage

Parameters	**Severity of damage**			
	Low (1)	**Medium (2)**	**High (3)**	**Very high (4)**
Flood duration	Less than one hour	Several hours	More than a day	More than aweek
Trash & Debris	Low	Medium	More	Massive
Texture & Saturated hydraulic conductivity (inch/hour)	Fine < 0.5 in/hr	Medium 0.51-1.00	Coarse 1.00-3.00	Very Coarse >3.00
Elevation (meter)	>80	20-80	5-20	<5
pH (saturated extract)	6.1-7.3	5.6-6.0; 7.3-8.0	5.1-5.5; >8.0	<5.0
ECe (dSm^{-1})	<8.0	8.0-16	16-32	>32
ESP (%)	<15	15-25	25-45	>45
SAR (ratio)	<6	6-12	12-24	>24

Table 2: Weightage for the selected parameters

Parameters	Weightage
Flood duration	3
Trash & Debris	1
Texture & Saturated hydraulic conductivity (inch/hour)	4
Elevation (meter)	2
pH (saturated extract)	2
ECe (dSm^{-1})	4
ESP (%)	4
SAR (ratio)	3

The severity of damage map of the affected areas was prepared by summing the damage ratings of various parameters multiplied with their respective weightage in GIS environment.

$$\text{Severity of damage} = \sum_{i=1}^{n} Pr \times Wi \qquad (2)$$

Where, Pr is the damage rating of a parameter, Wi is the weightage and n is the number of parameters used in the assessment. Table 3 shows the severity and degree of damage.

Table 3: Ratings for assessing the severity of damage based on weighted index

Index value	Severity of damage	Priority class
10.00 – 12.00	Very low damage	Low
12.01 – 13.00	Low damage	Moderate
13.01 – 15.00	Moderate damage	High
> 15.00	High damage	Very high

Ground verification was carried out after data analysis and severity map preparation. Crop growth in the affected and unaffected areas was observed to verify the accuracy of assessment. Further, NDVI for pre (December 24, 2004) and post *tsunami* (January 18, 2005) satellite data was prepared. Mean NDVI values of 3 × 3 window size was computed for selected locations and compared.

IRS-1D (LISS III) data was used to prepare the land use/land cover map of south Andaman. The major classes identified from the land cover/land use map of south Andaman are forest, agricultural land, marshy/swampy land, settlements, rocky edges of islands and sand deposits (Fig. 2a). A synoptic view of the land cover/land use map shows that majority of the area (90 %) is under forest cover. The soil series identified in the revenue areas are Dhanikhari, Garacharma, Wandoor, Schoolline, Pahargaon, Rangachang and Tushnabad (Fig. 2b).

Tsunami has affected areas around the coast with major impact on the eastern coast. The total geographical area of south Andaman is estimated to be 143087 hectares. In which, agricultural area is only 10466 hectares. Out of which 1408 hectares (14 % of cultivated area) have been affected by *tsunami* with varying severity of damage.

Even though *tsunami* has affected all the soil series Dhanikhari series experienced severe impact which accounted for 25 % of its own geographical extent. The lowest impact was observed on Tushnabad series which is only 2 % of its geographical area (Table 4). Out of the total area of affected soils (2994 ha) Dhanikhari series accounted for 48 % (1450 ha) followed by Wandoor (18 %), School line (13 %) and others. The impact was found to be higher on Dhanikhari series as its spatial extent is on the eastern side of the island closer to the coast. It is also evident from the figure that major areas under cultivation are in Dhanikhari, School line and Wandoor soil series.

Sea water intrusion into the agricultural lands resulted in the deep salinization of soils and adversely affected all kinds of vegetations. An early assessment of coastal rice fields in the southern part of Sri Lanka and adjoining salty marshes indicated that they are covered with marine silt containing sulphurous substances (IUCN, 2005). Further, there

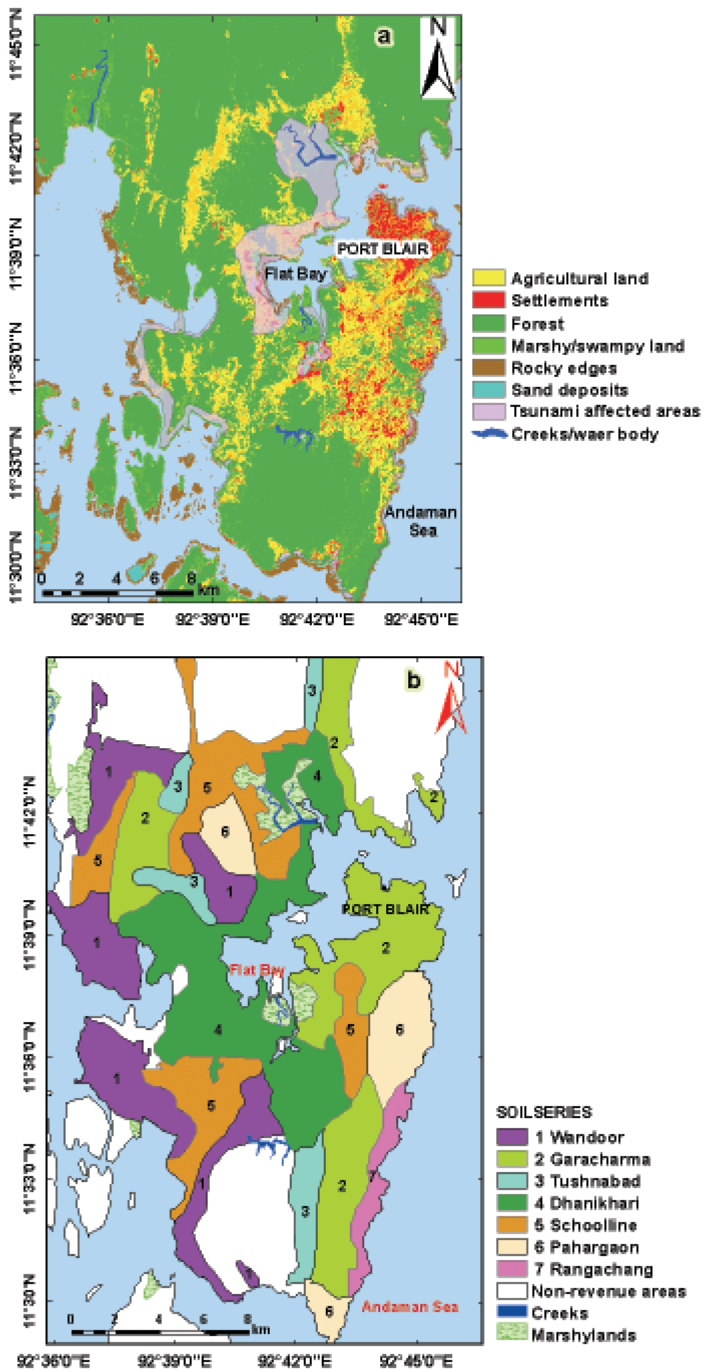

Fig. 2a. Land use/land cover map of south Andaman
Fig. 2b. Soil series of south Andaman

was a wide variation in the spatial distribution of duration of sea water flooding in south Andaman. The *tsunami* impact on surface soils of major affected soil series are given in Table 5.

Table 4: Soil series of south Andaman affected by *tsunami*

Soil series	Soil area (ha)	Affected (ha)	%
Dhanikhari	5833	1450	25
Garacharma	8167	327	4
Pahargaon	2259	156	7
Rangachang	731	111	15
School line	4641	385	8
Tushnabad	1668	32	2
Wondoor	6877	532	8

0.173) between the spatial distribution of ECe (Fig. 3b) and the duration of flood was not significant, but in gently sloping to flat lands towards the coast, ECe has increased with duration of flood and indicated a localized distribution.

SAR was found to be 2.69 in the unaffected areas and it has increased tremendously in the *tsunami* affected areas (19.14) indicating huge amounts of sodium addition from sea water into the soil. Among the three soils series, Dhanikhari has recorded maximum SAR value (6.48 – 48.18) followed by Wandoor and School line. However, there is no significant pattern in the spatial distribution of SAR (Fig. 3c) in the *tsunami* affected areas. It appears that soil texture, distance from the coast and the direction of sea water intrusion might have influenced the spatial pattern of SAR. The excessive concentration of sodium ions in the soil may create sodicity problem leading to structural deterioration and poor infiltration.

Table 5: Surface soil properties of selected soils of south Andaman

Soil series	Condition	pH	ECe	SAR	ESP
Wandoor	Un-affected	4.9-6.9	0.89-2.01	2.64-3.35	4.20-5.01
	Affected	5.4-7.1	16.89-44.1	4.5-28.05	6.7-40.37
School line	Un-affected	5.8-6.9	0.72-0.85	1.60-2.15	2.40-3.22
	Affected	6.4-7.2	8.01-10.50	10.69-25.60	13.82-27.75
Dhanikhari	Un-affected	4.5-6.7	1.58-9.81	1.99-3.77	2.97-5.63
	Affected	5.2-7.2	6.68-33.2	6.48-48.18	9.63-67.4

The results revealed that in the affected areas soil pH (6.93) has slightly increased as compared to the unaffected areas (6.35). The spatial distribution of soil pH (Fig. 3a) in the *tsunami* affected areas indicated that the coastal areas are mildly alkaline to slightly acidic and becomes strongly acidic away from the coast. The soil salinity was measured from the soil saturation paste extract and the data indicated that ECe has increased in all the *tsunami* affected areas (17.89 dSm^{-1}) as compared to the unaffected areas (5.27 dSm^{-1}). The correlation (r =

As in the case of SAR, exchangeable sodium percentage (ESP) also increased and followed similar spatial distribution pattern (Fig. 3d). Even though, sea water deposited lots of sodium into the surface soil, presence of other exchangeable cations in the exchangeable sites and CEC (cation exchange capacity) will also influence the ESP. Positive and significant correlation (r = 0.518) observed between

ESP and duration of flooding indicated that in areas of longer duration of flooding large amounts of sodium salts have been added into the soil.

data is very much useful in identifying flooded areas, especially where sea water inundation lasted for several days. Large trash and debris were found in

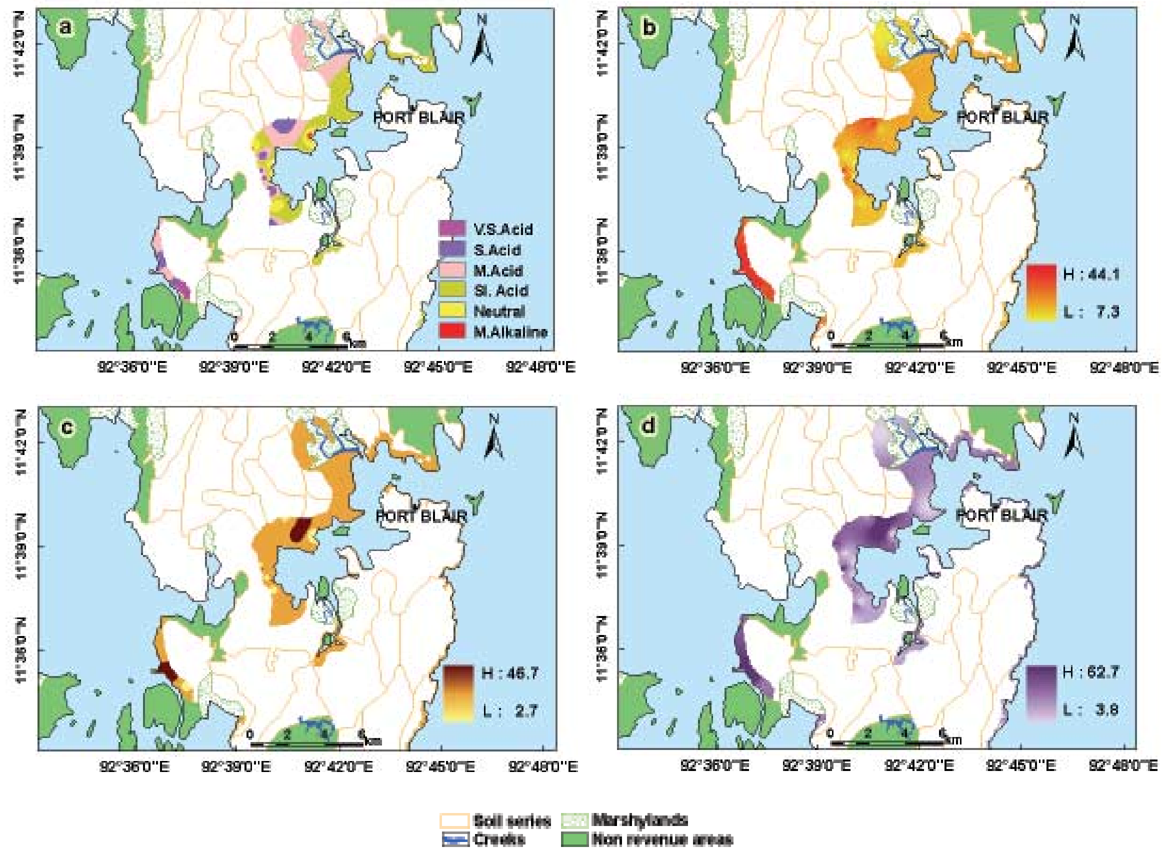

Fig. 3. Distribution of (a) Soil pH (b) Electrical conductivity (dSm^{-1}) (c) Sodium adsorption ratio and (d) Exchangeable sodium percentage in *tsunami* affected areas of south Andaman

The duration of flood (Fig. 4a) and trash and debris deposited on the surface of the soils are the clear manifestation of the effects of *tsunami*. Generally, the impacts of sea water flooding decreased away from the coast and with increase in elevation. The spatial distribution of duration of flooding and DEM shows that sea water also entered through the creeks and inundated large portions of cultivated areas. The remote sensing the eastern coast with gently sloping to flat lands where there was a sudden surge of sea water.

A comparison between the NDVI image of pre and post *tsunami* has indicated a reduction in the mean NDVI values of affected areas (Table 6). This is due to increase in salt content of cultivated surface soils in the affected areas which caused drying of vegetation. During the field verification of the affected areas in November, 2005 rice crop was found to be more succulent and severely infested with stem borer indicating the saline nature of soils. Because of succulent nature of crops NIR reflectance will be more and the difference between NIR-Red in the affected areas will increase than the unaffected areas. This effect was also observed in the pre *tsunami* remote sensing data of coastal saline soils where rice is predominantly grown.

Table 6: NDVI values of pre and post *tsunami*

Locations	pre-tsunami	post-tsunami
Mithakhari	0.535	0.423
Guptapara	0.571	0.281
Garacherma	0.461	0.402
Dundas point	0.226	0.027
Namunaghar	0.145	0.070
Chauldari	0.446	0.211

Note: values are average of 3×3 window size

The impact of *tsunami* is analyzed based on the changes in soil properties and field level damages which are sensitive indicators. The affected areas can be prioritized for management by quantifying the damages through ranked indicators using GIS software. This will help the planners, policy makers, scientist and farmers to adopt a selective approach considering the vastness of affected areas, severity of damage and constraints of resources.

The severity of damage map (Fig. 4b) for the *tsunami* affected areas of south Andaman was prepared by integrating the weighted thematic layers. It varies spatially across different soil series and no typical pattern was observed. Severe damage was observed around Mithakhari, Craikabad, Manglutan and Guptapara areas and it should receive very high priority for soil and crop management. These areas should be monitored closely and proper agricultural rehabilitation plan has to be devised for the future to restore and sustain the productivity of the soils. The areas surrounding the severely damaged areas and rest of the affected coastal areas are grouped as moderately damaged, which require high priority in management of soil and crop, especially leaching of salts using fresh water to restore agriculture. The affected areas away from the eastern coast and around Namunaghar suffered low level of damage and the remaining areas experienced very low level of damage. These areas require moderate to low priority. The suitability of these soils for various cropping pattern is a question and require detailed soil survey.

NDWI image derived from remote sensing data coupled with ground verification and other lateral inputs of pre and post *tsunami* have the potential to delineate the affected areas. The mean NDVI values have decreased in the affected areas. The impact of *tsunami* on agricultural lands can be assessed using the indicative parameters used in this study. Preparation of severity of damage and prioritization maps using RS and GIS is a useful tool to manage *tsunami* and like incidence in the future. The tragic memory has taken a backseat and farmers have resumed their normal farming activities. However, close monitoring of the soil and crop performance using high resolution satellite data and ground monitoring are necessary to restore the sustainability of the agro-ecosystem in this fragile region.

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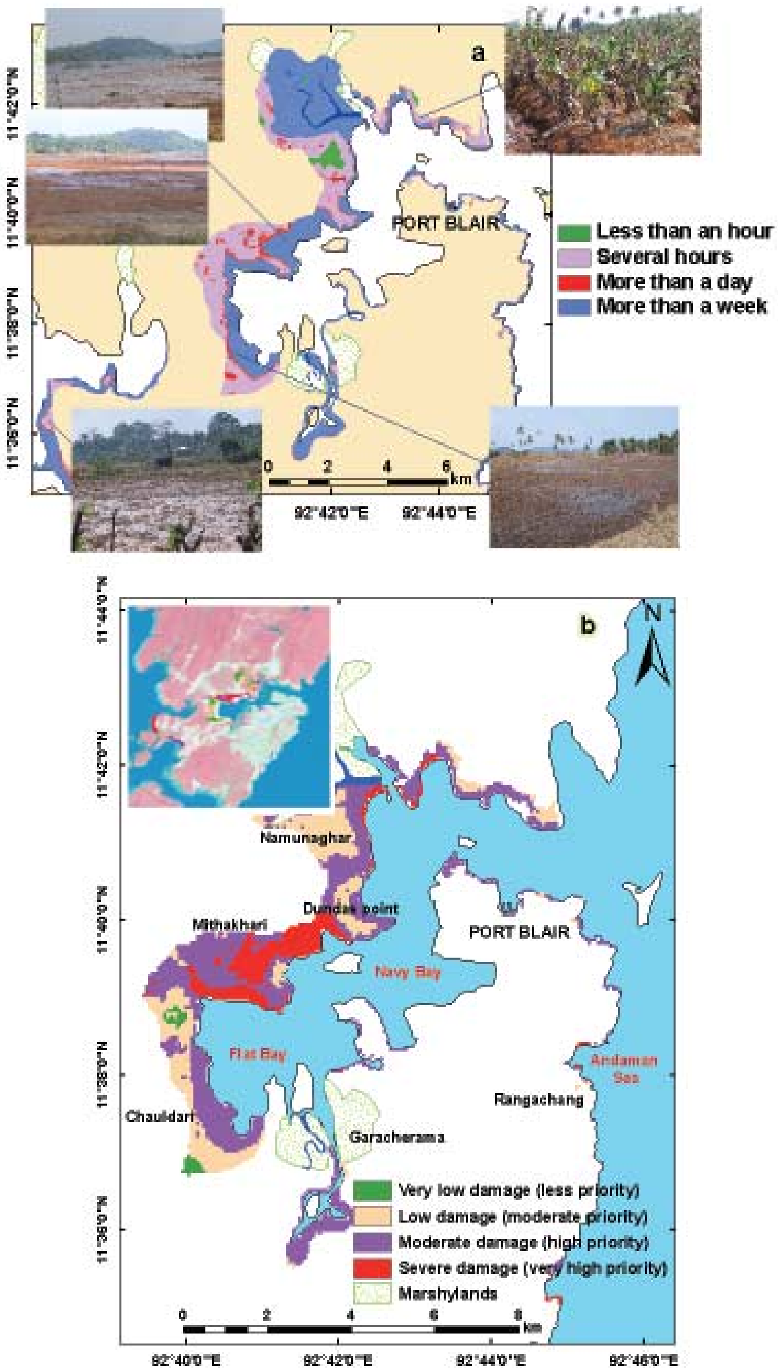

Fig. 4a. Duration of flood map
Fig. 4b. Severity of damage map of *tsunami* affected areas of south Andaman

References

Blasco, F. and Bellan, F.M. (1992). Estimating the extent of flood in Bangladesh using SPOT data. *Remote Sensing Env.*, **39**: 167-178.

Chatterjee, C., Kumar, R. and Mani, P. (2003). Delineation of surface waterlogged areas in parts of Bihar using IRS-1C LISS-III data. *J. Indian Soc. Remote Sensing*, **31(1)**: 57-65.

Dwivedi, R.S., Sreenivas, K. and Ramana, K.V. (1999). Inventory of salt-affected soils and waterlogged areas: a remote sensing approach. *Int. J. Remote Sensing*, **20(8)**: 1589-1599.

Food and Agricultural Organisation (2005). A Framework for reclamation action plan for affected soils (version 1), FAO, Rome, Italy.

Ganeshamurthy, A.N., Dinesh, R., Ravisankar, N., Nari, A.K. and Ahlawat, S.P.S. (2002). Land resources of Andaman and Nicobar Islands. Central Agricultural Research Institute, Port Blair, India.

Goyal, V.C., Jain, S.K. and Pareek, N. (2005). Water logging and drainage assessment in Ravi-Tawi irrigation command (J&K) using remote sensing approach. *J. Indian Soc. Remote Sensing*, **33(1)**: 7-15.

IUCN (2005). Early observation of tsunami effects on wetlands and water resources. The conservation union, Gland, Switzerland.

Jackson, M.L. (1973). Soil Chemical Analysis, Prentice Hall of India Pvt. Ltd., New Delhi, India.

McFeeters, S.K. (1996). The use of Normalised Difference Water Index (NDWI) in the delineation of open water features. *Int. J. Remote Sensing*, **17(7)**: 1425-1432.

Nagarajan, R., Marathe, G.T. and Colling, W.G. (1993). Identification of flood prone regions of Rapti river using temporal remotely sensed data. *Int. J. Remote Sensing*, **14(7)**: 1297-1303.

Navalgund, (2005). Sumatra Tsunami of December 26, 2004. *J. Indian Soc. Remote Sensing*, **33(1)**: 1-6.

Rao, D.P. (1990). IRS-1A application for land use/land cover mapping in India. *Current Science*, **61**: 153-160.

Ray, S.S., Dadhwal, V.K. and Navalgund, R.R. (2002). Performance evaluation of an irrigation command area using remote sensing: a case study of Mahi command, Gujarat, India. *Agricultural Water Management*, **56**: 81-91.

Sharma, P.K., Chopra, R., Varma, V.K. and Thomas, A. (1996). Flood management using remote sensing technology: the Punjab experience. *Int. J. Remote Sensing*, **17(17)**: 3511-3521.