Journal of the Andaman Science Association Vol. 19(1):65-74 (2014)
ISSN 0970-4183, Printed in India

LAND DEGRADATION AND ITS SPATIO-TEMPORAL CHANGES INDUCED BY NATURAL EVENTS IN ANDAMAN ISLANDS

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ABSTRACT

Land degradation has emerged as a global issue which necessitated appropriate techniques to monitor and technologies to manage them. In the present study changes in land degradation status (2004 – 2013) in Andaman Islands was carried out using remote sensing data in addition to assessing the effect of tsunami and its after effect on land degradation. The island suffers mainly from water erosion, acidity, coastal water logging and salinity of varying degrees. The results indicated that salinity and water logging have become severe from slight in the meantime it recorded 25% increase in area. Similarly erosion has become moderate from slight wherein 10% increase in coastal erosion was observed. Agricultural areas recorded the maximum increase in soil erosion at 28.5 t/ha in the post tsunami period while it was only 20.5 t/ha in 2004 followed by plantation crops. Raised beds has helped to leach out the salts resulting in significant reduction in salinity, SAR, Na^+, Ca^{2+}+Mg^{2+}, Cl^- and SO_4^{2-} level.

Key words: land degradation; remote sensing; tsunami impact; management; BBF

INTRODUCTION

Land is one of the most important natural resources necessary for the survival and well being of mankind which encompasses soil, water, surrounding environment and other surface features. The degradation of which will not only affect the land productivity but the livelihood of people who depend on it. Therefore land degradation and desertification emerged as an issue of global concern and has been given special prominence since the United Nation Conference on 'Environment and Development' in 1992. Apparently, over the last two decades, much research has been done on land degradation and its impact on biodiversity and productivity of soils (Eswaran *et al*., 2001). But, the type and the process of land degradation are location and region specific, therefore, understanding and managing land degradation at global level should essentially covers regional perspectives of land degradation.

Land degradation refers to a decline in the soil productivity through adverse changes in nutrient status, soil organic matter, structural attributes, and concentration of electrolytes and toxic chemicals (Lal and Stewart, 1994). In most of the definitions human interference was given prominence (UNEP, 1992 to define the land degradation. However, studies have also shown that the perceived land degradation can be attributed to natural factors rather than human induced land degradation especially in dry land areas (Nicholsen, 2005; Wessels *et al*., 2007). It has been observed from various global level studies on land degradation that no single cause is dominant in all the places or regions. The principal soil degradation processes include physical (e.g., decline in soil structure, crusting, compaction, accelerated erosion), chemical (e.g. nutrient depletion, elemental imbalance, acidification, and salinization) and biological (e.g., depletion of soil organic mater, reduction in the activity and species diversity of soil microorganisms) (Lal, 1994). But, soil degradation is a complex process which is more pertinent to coastal and island regions which have become more vulnerable to degradation induced by global climate change (FAO, 1998) and natural events such as tsunami which was prominently evidenced from the Indian Ocean tsunami of December 2004.

Land degradation has become a major concern in the tropical islands of Andaman, India as it directly affects the livelihood of thousands of people and threatens the sustainability of island ecosystem as a whole. The cultivated land available before 2004 tsunami was 50,000 which was shrunk by 14% due to land degradation and changes imposed by tsunami and its after effects. In addition there has been a perceptible change in settlement locations and cultivation of hill slops in the post tsunami period resulting in soil erosion and sedimentation of drainage net works. At the same time assessment of vulnerability to tsunami and land degradation following appropriate method and data sources is prerequisite for its proper management. Remote sensing techniques have been successfully used to map land degradation ever since these data were made available (Dwivedi *et al.,* 1988; Rao *et al.,* 1997) after the launching of LANDSAT-1 in 1972. The main advantage of using remote sensing data is the synoptic view of large areas and the possibility of image enhancement, information extraction and classification by using digital image processing. The capabilities of geographical information system can also be used to integrate spatial and non-spatial data to spatially analyze and interpret the results. Therefore the present study was aimed at assessing the land degradation status, vulnerability of Andaman Island to tsunami induced changes in soil physico-chemical properties and land degradation.

MATERIAL AND METHODS

The study comprised of assessment pre and post tsunami land degradation status using remote sensing and field survey, quantifying the effect on soil physico-chemical properties by laboratory analysis and study the spatio-temporal pattern using geographical information system. A case study was also conducted to assess the land degradation due to soil erosion.

The study area

About 1200 km east of the Indian mainland in the Bay of Bengal, between the geographical location of 8° to 14° N and 92° to 94°E, lies the Andaman Islands (Fig. 1). The Andaman Islands experiences a hot humid tropical climate with isothermic temperature regime as the difference between the annual maximum and minimum temperature is less than 5° C. The average annual rainfall is about 3100 mm with maximum rainfall occurring during the months of May to November. As these islands are situated close to the equator intensive solar radiation is received which favours very high rate of evapo-transpiration. Moreover, during dry months it far exceeds the rainfall resulting in water deficit condition. The major land forms are longitudinal hills, hill slopes, mid hill valley and coastal plains. Out of the total geographical area of 6408 km^2 nearly 87.8% is under forest cover and very less area is available for agricultural activity (DES, 2011). Rice, pulse and vegetables are cultivated in the narrow coastal plains and mountain valley while plantation crops like coconut, arecanut and spices are grown mostly in the side slopes of the longitudinal hills. This island harbours one of the most unique and rich marine and terrestrial biodiversity in the world.

Data sources

Standard products of Resourcesat - 1 LISS-III (Indian Remote Sensing Satellite) + PAN merged data of February – March 2004 and 2005, Resourcesat - 2 LISS-III of November – February 2012-13 pertaining to the study area were used. All the satellite images were geometrically corrected to the Universal Transverse Mercator coordinate system, WGS 84 datum and integrated with district vector layers in a geographical information system (Arc GIS ver 9.3). Ancillary data sources *viz.* topo sheets and forest management plan document were also used. Merged false colour composite (FCC) image, global positioning system (GPS) and Survey of India topo sheets (SOI) were used for ground truthing. The data on the location of various ground features was collected and marked on the topo sheet.

Image enhancement and visual interpretation

The image characteristics, such as colour, tone, texture, pattern, shape, size, location and association were used to visually delineate various land degradation categories on 1:25,000 scale. In this study six classes at level 2 were adopted for land degradation and land cover classification scheme. Terrain features were also used for improving the classification accuracy. The interpreted details were field verified for accuracy assessment. Corrections were made wherever necessary and soil samples were collected from different land degradation classes for soil characterization. The apparent contrast between soilscape features in the image was accentuated by using digital enhancement techniques such as contrast stretching and spatial filtering. This increased the amount of information that can be visually interpreted from the raw image data. The area statistics for different features were also computed using utility function.

Degradation classes

The image interpretation and field survey of the study area indicated that the area is mostly suffers from water erosion, water logging and chemical degradation. The chemical degradation was divided into acid sulphate soil, salinity and acidity. Each sub class (level 2 classifications) is assigned a severity class after field verification and laboratory analysis such as e1, e2, e3, e4 for erosion (Sehgal *et al.,* 1987). Oldeman (1994) also gave four similar types of degradation classes and the intensity was measured as light, moderate, strong and extreme.

Soil erosion model

Soil erosion caused by rainfall has become a concern in the post tsunami period which can be estimated either qualitatively by visual observation or quantitatively by measurement and modeling. There are several models available to quantify soil erosion on different scale and time period. Morgan *et al.,* (1984) have developed a method to predict annual soil loss from field-sized areas on hill slopes which are pertinent to these island conditions. The model characterizes the terrain using the DEM and uses multi temporal remotely sensed data to account for vegetation properties and soil moisture changes. The model estimates annual soil loss by evaluating both rainfall soil detachment and sediment transport over the soil surface. In the present study the model parameters calculated and standardized for Andaman condition by Velmurugan *et al*., (2007) was used to estimate soil erosion over Tushnabad, South Andaman.

Sampling for degradation assessment

Two different sets of samples were collected during the course of the study in order to assess the land degradation status, changes in soil and water characteristics. First, one time soil and water samples were collected during February-March 2013 from all the seven degradation classes delineated using remote sensing data to determine the type and severity of degradation. Each sample was a composite of three samples collected from each land degradation class.

Secondly, ten surface soil samples (0-30cm) were collected from degraded tsunami affected areas by following stratified random sampling method during February - March 2005 (immediately after tsunami), 2010 and 2013 from the same sites to ascertain the changes occurring in soil salinity. The soil samples were air dried, powdered and sieved through a 2 mm sieve.

Analysis

The sieved soil samples (< 2 mm) were analyzed for electrical conductivity (ECe), pH, cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^-) in the saturation extract using standard methods (Page *et al.,* 1982). Sodium adsorption ratio (SAR) was calculated using the following equation (Havlin *et al*., 1999).

$$SAR = [Na+] / sqrt [(Ca^{2+} + Mg^{2+}) /2] \qquad (1)$$

Statistical analysis

Statistical analysis was carried out using Agres software (V 7.01). Descriptive statistical parameters such as mean, standard deviation and standard error were also calculated for comparison. One way analysis of variance was used to compare the mean values of various parameters. Significant differences were detected based at probability level of 5%.

RESULTS AND DISCUSSION

Degradation status and vulnerability to tsunami

Remote sensing based estimates of land degradation status for 2004, 2005 and 2013 was carried out and is presented in Table 1. The results indicated that in Andaman Islands seven categories of land degradation were recognized. It was observed that some of these land degradation categories exist together based on the dominating process particularly salinity with water logging, acidity with erosion, saline-acidic and water logging with marshyness. Similar remote sensing based approach was used to study the land use land cover change impact on soil properties by Biro *et al.,* (2013). In 2004, slight erosion (e1) along with soil acidity was the predominant degradation class (78%) occurring in the forested areas followed by water logging and marshy condition (12%) in the sea front of the island. The coastal saline-acidic soils generally extend upto 1-2 km inland but at certain places brackish soil conditions persist 4-5 km inland coupled with seasonal water logging. Setia *et. al.,* (2013) has shown that remote sensing image classification can be used to discriminate severity levels of salt-affected soils which were significantly related with ECe. The high salinity critically affected the productivity of rice (2.2 t/ha) in the coastal degraded areas as a result only long duration photosensitive variety (C-14-8) were grown during the rainy season (July-December). Soil acidity was a common constraint because of hot and humid climate favouring intensive weathering and leaching of the basic cations. Soil acidity also affected plant growth and other microbial processes leading to decrease in the biological productivity of these soils.

Table 1. Changes in area of different degradation types and its severity

S.No	Degradation type	2004		2005		2013	
		Area (ha)	Severity class	Area (ha)	Severity class	Area (ha)	Severity class
1	Coastal erosion	1348	Slight (e1)	1479	Moderate (e2)	1650	Moderate (e2)
2	Erosion	22321	Slight (e1)	22380	Moderate (e2)	22660	Moderate (e2)
3	Erosion and acidity	452241	Moderate (e1, m.a)	451374	Moderate (e1, m.a)	450374	Moderate (e1, m.a)
4	Acid-saline soil	5686	Severe (A3)	5382	Severe (A3)	5540	Severe (A3)
5	Water logging and salinity	8611	Moderate (w2, s1)	10637	Severe (w3, s2)	9854	Severe (w3, s2)
6	Water logging and degraded mangroves	67522	Slight (w1)	66321	Slight (w1)	67925	Moderate (w2)
7	Seasonal water logging	16779	Slight (w1)	16935	Severe (w3)	17800	Severe (w3)

Systematic soil survey of Andaman Islands have described eight soil series covering three soil orders (Ganeshamurthy *et al.,* 2002) which also documented the pre-tsunami physico-chemical characteristics of these soil series carried out (Table 2). The results showed that Garacharma was the major soil series characterized by soil acidity, erosion and low nutrient content which was followed by wandoor soil series characterized by poor drainage and coastal salinity. Swarnam *et al.,* (2010) have identified waterlogging, acidity, salinity and low nutrient reserve as the major soil factors causing land degradation in different soil series of Andaman Islands. Soil acidity was a common constraint in all the series except Rangachang, because of hot and humid climate favouring intensive weathering and leaching of the basic cations.

These were in dynamic equilibrium with natural forces and human activities. However, the December 2004 tsunami has severely affected and exposed the vulnerability of these islands. But the holistic measurement and quantification is difficult as it involves some approximation as well. Therefore, the impact of tsunami was inferred from the changes in extent and severity of these degradation categories in 2005 compared to the pre tsunami level. The results indicated that severity of salinity and water logging become severe from slight with an increase of 25% area. Similarly erosion has become moderate from slight with 10% increase in coastal erosion. Another phenomena imposed by tsunami was 1% increase in area under seasonal water logging and its severity (w3) which greatly restricted the agricultural activity forcing the abandonment of agriculture in low lying coastal areas. There was not much change in severity of acid saline soil however some of these areas have been converted into seasonal water logged areas after tsunami which further aggravated the degradation. Haque (2006) also reported coastal salinity and water logging as a major production constrain in the coastal areas of Bangladesh.

Table 2. Soil series of Andaman and its degradation status before tsunami

Soil series / (sub order)	pH (1:1)	ECe (dS/m)	CEC (c.mol(+) kg soil^{-1})	ESP (%)	Degradation status
School line (Fluvents)	5.9	1.36	10.88	13.13	Moderate erosion, low base status
Garacharma (Orthents)	5.7	0.64	16.28	13.91	Severe erosion, low nutrient status
Dhanikhari (Aquents)	5.1	3.92	14.84	15.14	Acid sulphate in nature, Low pH and P, toxicity of Fe and Al
Rangachang (Psamments)	6.7	0.73	12.62	10.92	Coarse texture, low nutrient reserve
Tushnabad (Aquepts)	5.3	0.59	17.27	13.24	Heavy texture, poor drainage
Pahargaon (Ochrepts)	6.1	1.35	12.02	8.29	Moderate to steep slope, moderate erosion
Wandoor (Ochrepts)	6.2	1.27	4.17	14.90	Heavy texture, poor drainage, coastal salinity
Little Andaman (Ustalfs)	6.3	0.83	8.64	12.57	Severe erosion, low nutrient and water holding capacity

Besides, the after effect also influenced the degradation through change in socio-economic activities of human beings. More importantly it paved the way for increased human activities linked to land degradation while it rejuvenated some of the natural cause of degradation such as erosion and sea water inundation. This can be inferred from the changes in extent and severity of degradation between 2005 and 2013 (Fig.1). Due to tsunami induced changes significant increase in area affected by water logging and salinity (0.2%) was observed followed by seasonal water logging (0.18%) and erosion (0.1%). Though the area under water logging and salinity (0.35%) increased due to tsunami but in 2013 the area has decreased due to improvement in drainage and construction of protective bunds in the sea front. The analysis further revealed that the area under moderate degradation has increased from 82.5% to 94.2% in 2013 indicating the increase in different degradation process in the islands (Fig. 2). Overall, the severity class has increased from 2.8% in 2005 to 5.8% in 2013 which is mainly due to tsunami induced degradation.

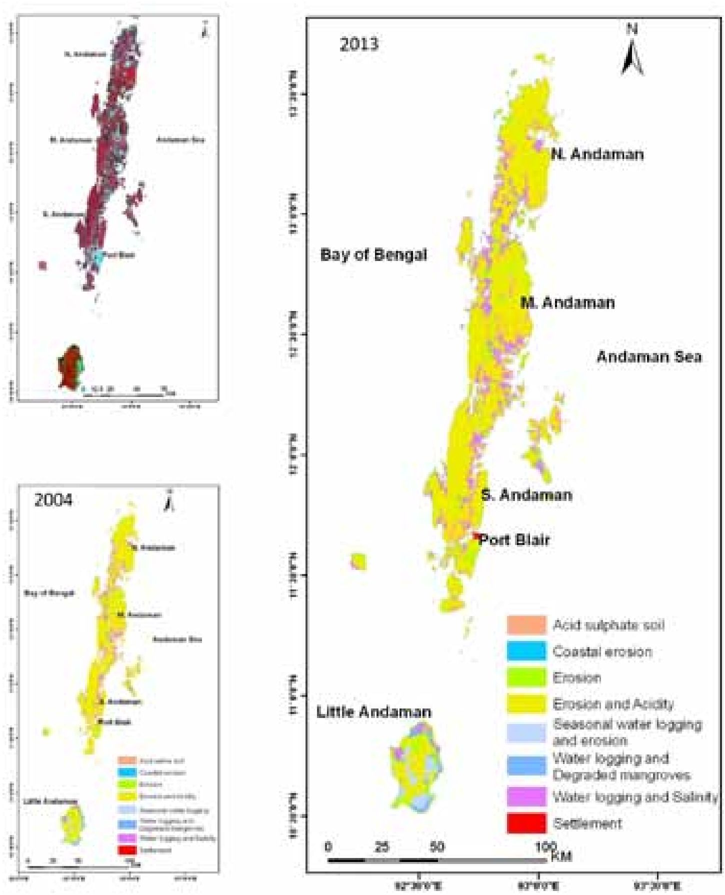
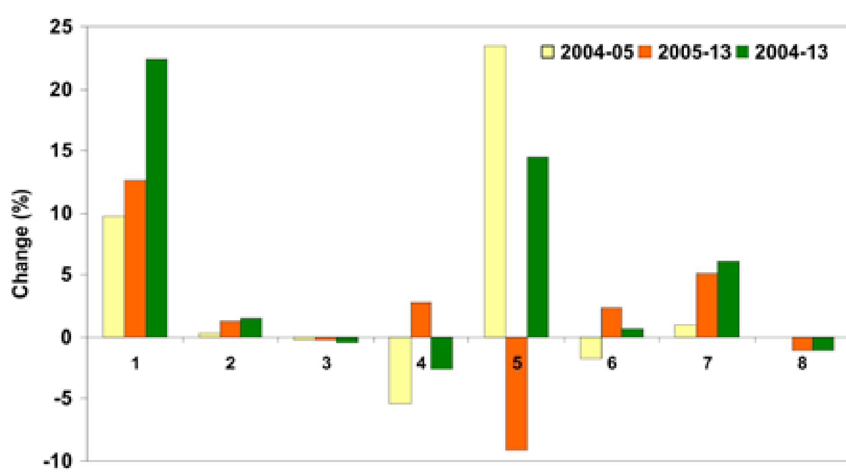


Figure 1. Status of land degradation in Andaman Islands



1. Coastal erosion 2. Erosion 3. Erosion and acidity 4. Acid sulphate soil 5. Water logging and salinity 6. Water logging and deg mangroves 7. Seasonal water logging 8. Undegraded

Figure 2. Percentage change in area due to tsunami and tsunami induced changes

Effect of tsunami on soil characteristics

The tsunami affected soil characteristics in the coastal areas by depositing soluble salt in the surface layers in addition to debris and sediments. The pHs (saturation extract) of surface soil immediately after tsunami varied between 6.63 to 7.46 and ECe from 8.2 and 26.9 dSm^{-1} (Table 3). This pointed to the fact that *tsunami* waves struck in a flash and receded from a sloppy areas and created water stagnation in lowlying areas leaving a layer of sodium and other soluble salts on the surface soil. Similarly soil Na^+, Ca^{2+}+Mg^{2+}, SAR, Cl^- and SO_4^{2-} content also became very high in the tsunami affected areas with wide variations. It was also observed from field survey that the increased level of soluble salt concentration in the subsurface resulted due to the percolation of soluble salts downward from the surface soil. Similar findings were reported by Rachman *et al*., (2005) on the effect of tsunami on farmland in Aceh, Indonesia. The SAR was found to be 48.11 with large variation observed in its spatial distribution in the tsunami affected areas indicating huge amounts of sodium addition from sea water into the soil. This could be attributed to difference in soil texture, distance from the coast and the direction of sea water intrusion (Velmurugan *et al.,* 2006).

Table 3. Changes in physico-chemical properties of degraded soil

Parameters	Tsunami affected (February 2005)	Current status 2013	
		No intervention	Raised beds
pHs	7.41 (0.16)[a]	5.93 (0.10)[c]	6.41 (0.06)[b]
ECe (dSm^{-1})	20.38 (0.94)[a]	1.82 (0.08)[b]	1.21 (0.06)[b]
Na^+ (me l^{-1})	146.20 (2.02)[a]	54.73 (1.93)[b]	32.80 (0.91)[c]
Ca^{2+}+Mg^{2+} (me l^{-1})	27.60 (0.71)[a]	19.58 (0.62)[b]	15.20 (0.74)[c]
SAR	48.11 (0.54)[a]	17.43 (0.74)[b]	11.75 (0.43)[c]
HCO_3^- (me l^{-1})	3.39 (0.11)[a]	1.50 (0.05)[b]	0.85 (0.04)[c]
Cl^- (me l^{-1})	124.50 (2.00)[a]	34.00 (0.92)[b]	27.60 (0.88)[c]
SO_4^{2-} (me l^{-1})	61.24 (2.89)[a]	31.70 (0.73)[b]	17.82 (0.85)[c]

Mean values, n=10; SE in parentheses; different letters within one row indicate a significant difference at $p<0.05$

Tsunami induced soil degradation

Though soil erosion is a natural process human disturbance particularly cultivation of hill slops and removal of ground cover resulted in accelerated erosion. The results obtained from the MMF erosion model studied over Tushnabad, South Andaman (Fig. 3) indicated that erosion has significantly increased in all the land uses in the post-tsunami period except in secondary evergreen forest. Among the different land uses agriculture recorded the maximum erosion with an average value of 28.5 t ha^{-1} in the post tsunami period while it was only 20.5 t ha^{-1} in 2004. Plantation and coastal areas have also contributed to the accelerated soil erosion. In 2013, maximum soil loss with high variation was estimated in agriculture land (30.7 t ha^{-1}) followed by plantation (23.7 t ha^{-1}) and coastal areas (21.4 t ha^{-1}). Even though the estimated annual erosion for secondary evergreen forest was low (4.6 t ha^{-1}), it recorded 100% increase in soil loss when compared to the pre tsunami level due to forest density reduction and disturbances. All these changes were attributed to the human activities in the post-tsunami period.

Although tsunami and rainfall are considered as natural hazards they have the potential to initiate or modify the process of degradation particularly under island conditions through series of human activities which accelerated the process of degradation. These are mostly post-tsunami activities aimed at adaptation

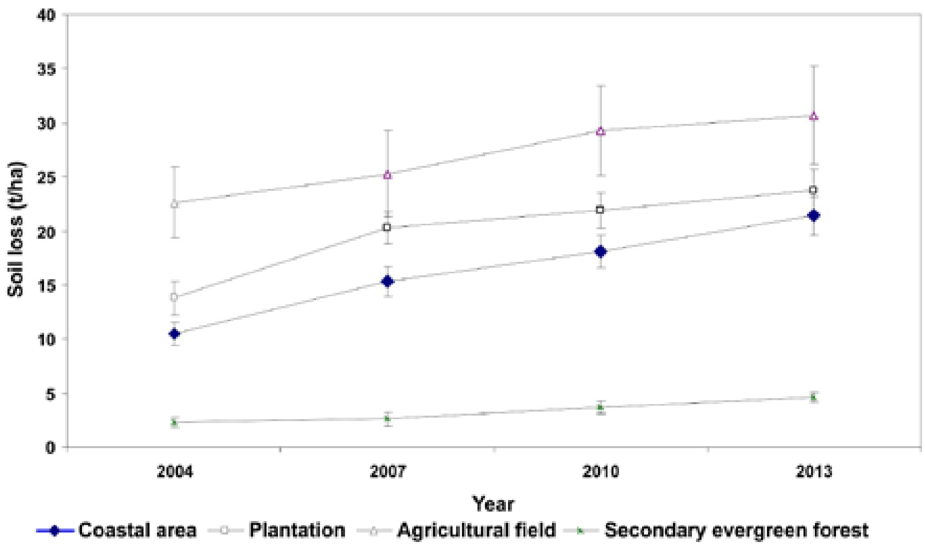


Figure 3. Changes in soil erosion of different landuse as predicted by MMF madel

or management in the changed situations unfolded by the tsunami. Among other things, the major degradation processes identified in the study area after tsunami were erosion and drainage congestion. Erosion in various land uses and physiographical conditions was accelerated by fragmentation, cultivation of hill slops and other erosion favouring practices. In the post-tsunami period, accelerated erosion from the hill slopes and blocking of water course by construction activities have favoured the deposition of sediment load in the drainage system resulting in drainage congestion and water logging.

Management of degraded coastal areas

The most important aspect of post tsunami degradation study was the management of land degradation and providing the people with a viable livelihood option. The interpretation of satellite data and laboratory studies revealed that water logging of coastal low land for a considerable part of the year associated with increasing salinity were the major problem concerning agricultural productivity. The raised beds (0.5 m) and furrow of 1 m width were made in the low lying degraded coastal areas improved the drainage of the beds. The beds were exposed to fresh water in the subsequent rainy seasons which resulted in significant ($p< 0.05$) removal of salts and toxic substances gradually from the beds compared to the surrounding degraded land apart from harvesting of rain water in the furrow. The soil pH of the beds determined in February 2013 was significantly higher (6.41) whereas it was moderately acidic (5.93) in the surrounding soils with no intervention. The salinity level (ECe) has significantly reduced to less than 2.0 dSm^{-1} from 20.36 dSm^{-1} measured after tsunami in February 2005. Significantly lower Na^{+}, Ca^{2+} and SAR values were observed in the beds than the surrounding areas. This could be attributed to leaching of soluble salts from soil surface by the rain water as the islands received higher amount of total annual rainfall of 310 cm.

CONCLUSIONS

The study showed that characterization of the surface properties and interpretations of multi-temporal satellite data from different sensor can be effectively used to assess the land degradation status even in Islands. Natural land degradation occurs predominantly as a result of erosion, leaching of base cations, sea water intrusion during high tide and tsunami. In the study area soil erosion and acidity were the predominant land degradation types occurring in 78.7% of the total geographical area followed by water logging.

Tsunami has severely affected the coastal areas which resulted in high salinity, increased concentration of soluble ions like sodium, chlorine, sulphate and sodium adsorption ratio. As a result, in the post tsunami period, the extent of water logging and soil salinity has increased by 0.22 % followed by seasonal water logging by 0.18 %. Among the different land uses agriculture recorded the maximum erosion with high variability in the post tsunami period which was only 20.5 t ha^{-1} in 2004. Although the annual erosion loss for secondary evergreen forest was low (4.6 t ha^{-1}) reduction in forest density in the post tsunami period was observed. The study found that water logging coupled with acid-saline condition was the major problem affecting crop production. In the intervention areas, raised beds has significantly reduced the salinity level and helped in restoring the productivity of land.

ACKNOWLEDGEMENTS

The authors place on record their gratitude to all the former Directors, Central Island Agricultural Research Institute, Port Blair for facilitating research and development in the coastal degraded areas. We sincerely acknowledge the support of scientist, research scholars, technical and supporting staff of Divison of Natural Resource Management.

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