Article

Are the sensitive zones degrading? A modelling approach using GIS and remote sensing

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Abstract
This present study assesses the sensitive zones and the forest density class prone to degradation using remote sensing and Geographical Information System (GIS) techniques in the Mudumalai Tiger Reserve (MTR), Southern Western Ghats (India). For assessing the vulnerability of degradation on different vegetation density, the drivers responsible for degradation were considered. LANDSAT MSS and IRS-LISS III satellite image was used to classify the vegetation density by applying Normalised Difference Vegetation Index (NDVI) technique and to create the sensitive zone maps for two different time periods, 1973 and 2010 using weighted overlay analysis. About 47% of the present forest area is under a low risk category, 24% is under medium risk category and about 7% (2517 ha) is under the high-risk category in 2010. The natural disturbances such as forest fire, wildlife grazing, and expansion of agricultural land induced by anthropogenic pressure over the decades are the reasons of forest cover change in Mudumalai. The area under no-risk zone has severely decreased, and medium and high risk zone has drastically increased when compared to 1973 where high prioritization for conservation planning is ideal.

Keywords weighted overlay analysis; vegetation density; risk zone; anthropogenic pressure; Western Ghats.

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1 Introduction

The forest resource is an important bearing on the environmental and ecological security for the country and its people (Zhang, 2007). Ecologically sensitive areas are identified with a flexible system of management and embedded with protected areas with an adaptive regime of regulation. The sensitive areas are aimed to attain more comprehensive than focusing merely on biodiversity richness or ecological fragility (Gadgil, 2011). The deforestation and degradation of forests arose due to the expansion of hill slope and valley agriculture, fire, clear-felling, grazing and encroachment, which result in constant stress and exploitation to the forest (Zhang et al., 2006; Zhang, 2012). Due to these heavy pressures, the forest cover of tribal and hill districts in India has lost 548 km^2 and 679 km^2 respectively in 2011 (FSI, 2011). Formal protection of natural resources in reserves has tended to be *ad hoc* favoring the biodiversity of areas that are least valuable for commercial use, in public tenure but earnest to reserve, most charismatic and with the least need for protection (Margules, 2002) which is quite important for the protection strategy.

The gross forest cover loss was accounted to be 0.6 % per year during 2000 to 2005 at global level (Hansen et al., 2010). Forest Survey of India assessed the country's forest cover as 692,027 km^2 (FSI, 2011), which represents 21% of the total geographical area, whereas Tamil Nadu covers 28,306 km^2. The total forest cover of Nilgiris was 56.3 % in 2009 (State Environment Report of Tamil Nadu, 2009). According to Myers et al., (2000), forest cover in India declining at the rate of 2.6 %. However, the rate of deforestation is highly debated. Few works has been done only in the selected areas of India which are under-going deforestation and degradation in India (Jha et al., 2000; Giriraj et al., 2008; Joseph et al., 2009; Reddy et al., 2009; Reddy et al., 2010), but did not specifically focus on sensitive zone mapping and the drivers influencing degradation using models. Modelling the sensitive zones is important for understanding forest cover dynamics in the reserve forest. These models can provide a better understanding of the factors that drive forest changes and generate future forest cover scenarios to support the design of policy responses (Achard, 2002). Therefore, a thorough research on ecologically sensitive regions would help us formulate better management strategies at the micro level by understanding the causative factors for the formation, use and maintenance of forests and to undertake effective management plan, which is known for its role in environmental protection and prevention of damage. To monitor the forest cover and the degradation pattern, remote-sensing offers consistent observation at a finer scale with more precision and in a cost-effective manner (Tucker, 2000) and it is considered to be an essential data source for the appraisal of natural environments as it provides valuable information for interpreting the landscapes. The study is aimed to produce a sensitive zone maps at different years in order to detect the changes that have taken place particularly in the settlements nearby to the forest and subsequently to analyse the trends in degradation pattern occur due to the expansion of agricultural lands over a period of 1973 and 2010.

2 Materials and Methods

2.1 Study area

The study focuses on a segment of Southern Western Ghats, Mudumalai Tiger Reserve (Mudu-Old; Malai- hill - ancient mountain), which is one of the most popular and the oldest wildlife sanctuaries in India. The sanctuary lies between 11° 32' - 11° 43'N latitudes and 76° 22'-76° 45' E longitudes and covers an area of 321 km^2 (Fig. 1). It lies in the tri-junction of the three southern states of India viz., Tamil Nadu, Kerala and Karnataka. There is a distinct rainfall gradient from east to west varying from 500 mm to 2000 mm. Mudumalai Tiger Reserve (MTR), primarily dominated by deciduous forests along with tropical semi-evergreen, moist deciduous, dry deciduous and dry thorn forests (Champion and Seth, 1968). Mudumalai is the most important for its socio-cultural because most of the tribal settlements and pilgrim sites are located inside the reserve forest, which results in one of the threatened habitats due to continuous human disturbances. Moreover, large tracks of forest are degraded and converted into agricultural lands. The objective of this study is to characterize sensitive zones, its rate of deforestation using remotely sensed data and to check whether the degradation occurs in the sensitive areas of MTR, Southern Western Ghats, India.

Fig. 1 Geographical location map of the study area in India.

Satellite images of LANDSAT MSS (1973) and IRS P6 LISS III (2010) are geometrically corrected using topographic maps in ERDAS Imagine 11.0 software. False colour composite image of the study area was generated from LANDSAT MSS and IRS LISS III with appropriate band combinations. The common uniformly distributed Ground Control Points (GCPs) were marked with root mean square error less than a pixel. For analyzing the degradation prone areas, several thematic layers were created for weighted overlay analysis. The conversion of forest often relates to physical accessibility variables. Accessibility to a road is a significant factor of deforestation. The role of road access was highlighted in predicting the location of deforestation in many areas, such as the Basho Valley, Northern Pakistan (Ali et al., 2005), Northern Thailand (Cropper et al., 2001) and the Congo Basin (Wilkie et al., 2000). The location of water affects to the location of cultivation; therefore, the proximity to water is closely related to deforestation. Permanent cultivation in the area seemed to be concentrated close to water. Bawa et al., (1997) found that deforestation was strongly correlated with the extension of cropland area in Asia and Latin America. Deforestation occurs due to important drivers like proximity to road, town and forest/non-forest in southern Cameroon (Merten and Lambin, 1997). Elevation, slope, proximity to road, settlement and proximity to forest/non-forest edge were the key factors of forest change in southeast Mexico (Mas et al., 2004). Topography often influences the spread and extent of forest conversion. For example, a case study in Costa Rica (Sader, 1988) found that as the slope gradient increased, deforestation decreased. The forest loss and degradation are associated directly with proximity to roads and villages upto 6 kms (Menon, 2001) that confirm the disturbing effect of roads by logging, mining, grazing, agriculture and urban development. By applying this technique, six priority themes have been selected by considering slope, settlements, vegetation, road, water body and pilgrim sites. Two kilometer buffer maps were created and the areas of highest priority are ranked based on its usage and importance. Survey of India toposheets were used to digitize thematic layers such as settlements, road networks, pilgrim sites and rivers using ArcGIS 10 software. A Digital Elevation Model of Mudumalai was generated by using Shuttle Radar Topography Mission (SRTM) data set and used for the estimation of slope factor and classified according to National Natural Resource Management System (NNRMS) slope classification. To assess the vegetation conditions, Normalised Difference Vegetation Index (NDVI) approach is used by applying following formula and classified as per Forest Survey of India density classification.

$$NDVI = NIR-R / NIR+R$$

where NIR = near infrared; R = visible red.

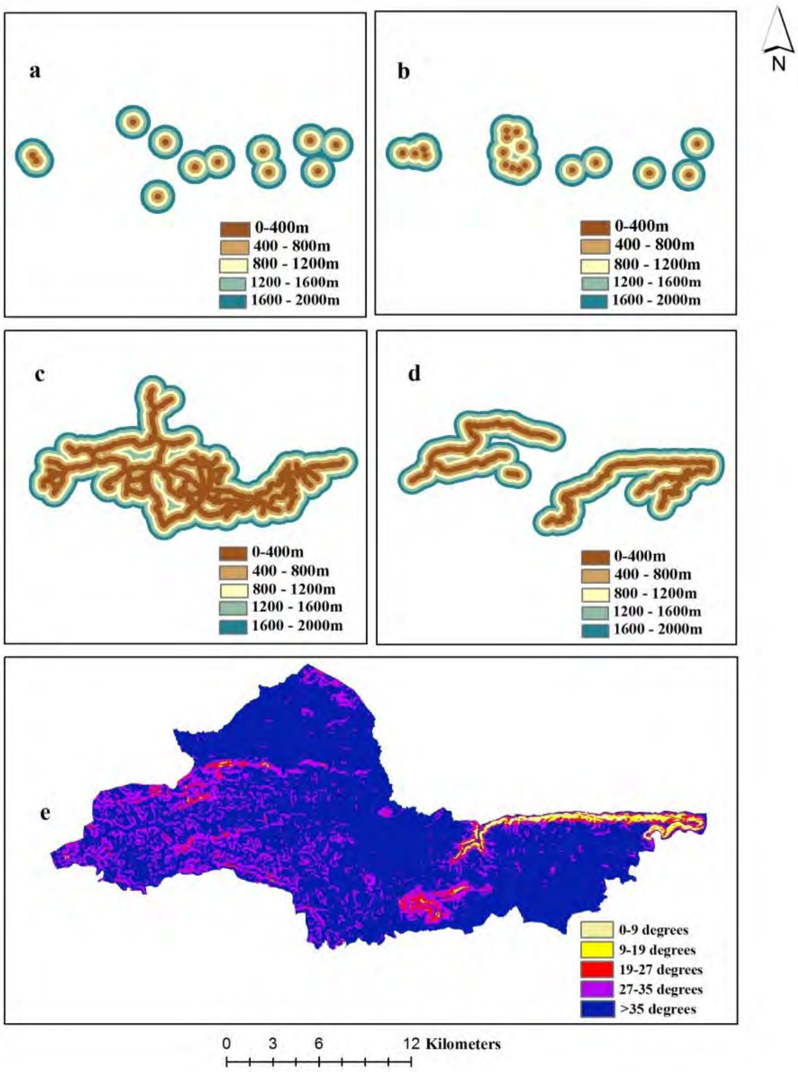

Fig. 2 a. Buffer zone of pilgrim sites; b. Buffer zone of settlements; c. Buffer zone of Roads; d. Buffer zone of major rivers.

Weighted overlay model with spatial analysis shows promise in its ability to integrate using different drivers on a complex problem to identify the degradation prone areas. It is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. The weighted overlay analysis helps in designing the conservation initiatives which provide in assigning the priority to macro-level drivers and weightage to each class, which has higher chances of causing deforestation in

Mudumalai. Though many input layers are used to create a single output layer, it is well known that all the input layers are not equally significant (Jayakumar et al., 2002). Based on this concept, more important layer has given high priority than the others. This is the advantage of weighted overlay approach, where one can assign weightage to each class and layers separately. Knowledge based weight assignment was carried out for each thematic layer, and they were integrated and analyzed using ERDAS imagine11.0. Weighted overlay only accepts integer rasters as input so continuous rasters have been reclassified as integer before they can be used.

$$L=PI*Wt$$

where L is the layer, Wt is the weightage of each class, and PI is the percentage of importance.

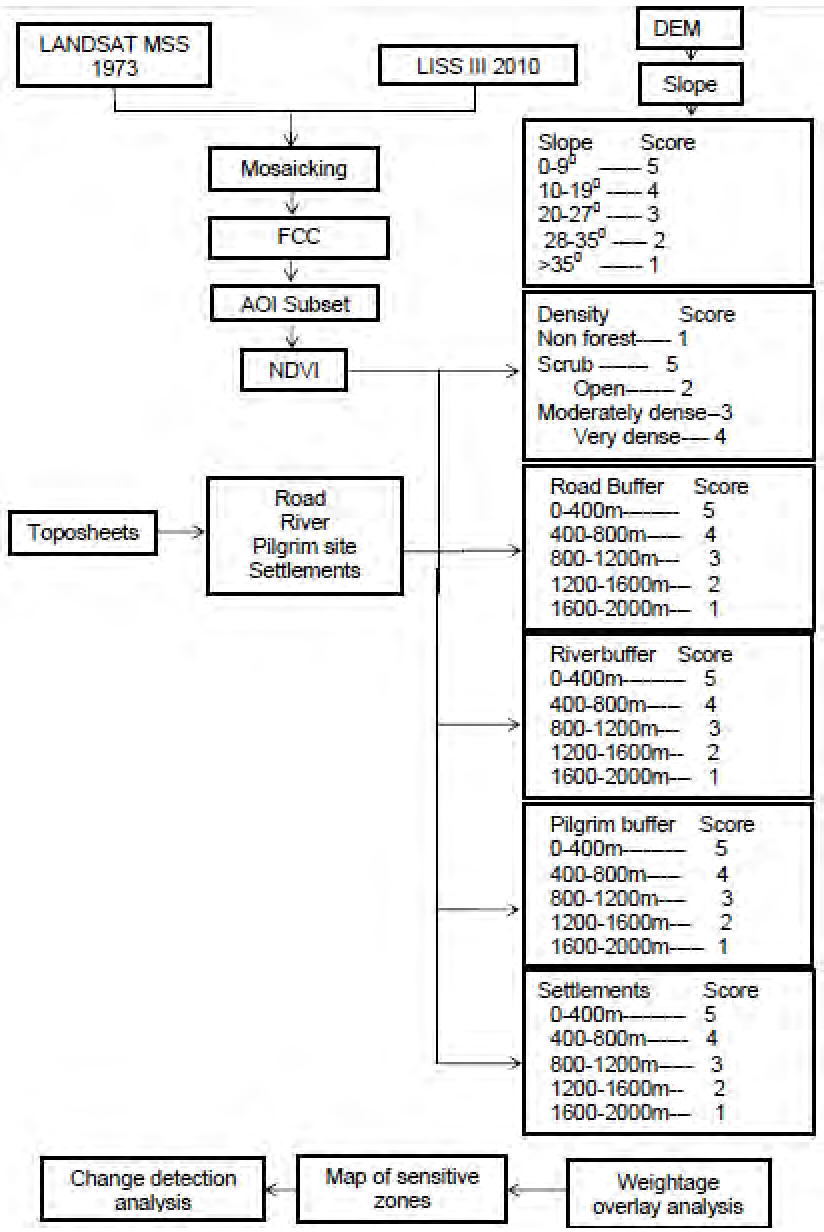

Fig. 3 Conceptual diagram illustrating the preparation of sensitive zones.

The anthropogenic pressures are likely to be high near the hamlets, road network (metalled, unmetalled) and pilgrim sites where the festival takes place every year; thereby people might create secondary and tertiary routes within the forest leads to increasing accessibility and vulnerability of the forest stand in the proximity. Spatial data of the six factors (road, river, settlements, slope, pilgrim site and forest density) were prepared as a set of GIS layers and overlaid together for final sensitivity classification for degradation. Two kilometer buffer for the road network, settlements, pilgrim site and rivers is generated, and high weightage was given to the zone nearer to the forest cover, accordingly to derive the sensitive zone (Fig. 2).

Each criterion and factor received a weight and a score which represented its relative importance in the zonation of sensitive areas, which are highly prone to degradation. Further analysis was done in raster-based format and was then reclassified into five classes using the ‘reclassify’ function. The topographical feature that mostly influences the deforestation process is the degree of slope, which was generated from SRTM satellite image. High slope areas is less used by the people, accordingly the weightage was given. Vegetation map of two years (1973 and 2010) was generated using NDVI, which is used as an indicator of vegetation condition. Forest density was calculated and classified into the five classes by assigning suitable weightage based on its usage. The sensitive zone maps generated for different periods are compared with the degraded areas using NDVI map of the latter period. The overall workflow is given in the Fig. 3.

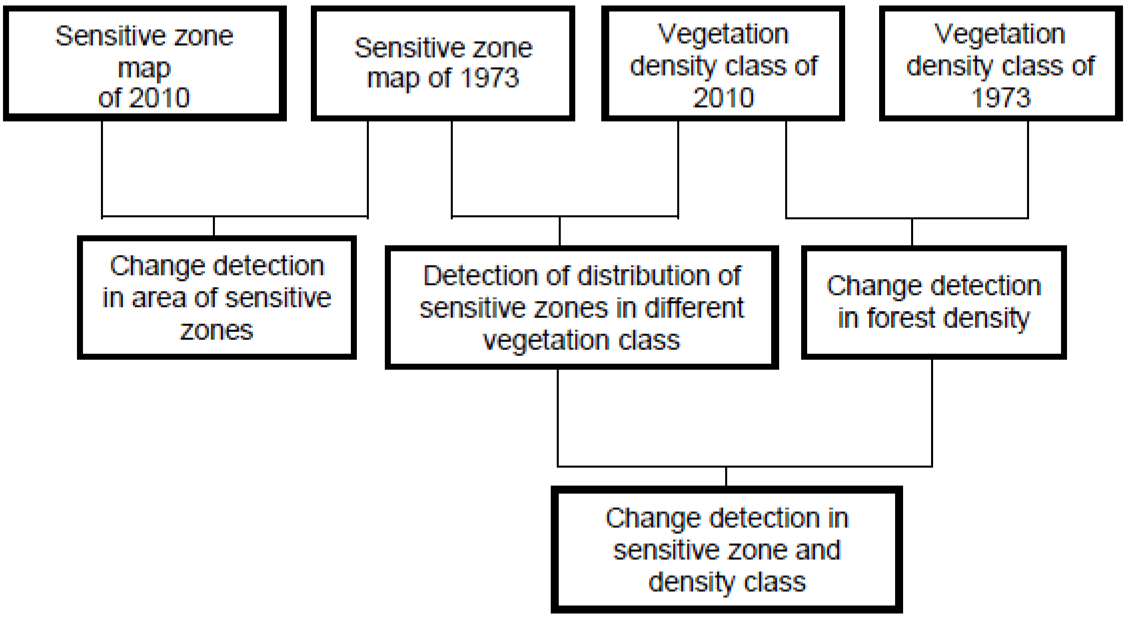

Fig. 4 Methodology flow chart for the change detection analysis.

Using the sensitive zone maps and forest density class maps for 1973 and 2010, change in the area between sensitive zones was calculated. Change in the area of forest density was calculated using NDVI of two time periods. Sensitive zone map of 1973 was compared with the forest density class of 2010 to identify the major distribution of sensitive zones between the forest density classes in 2010. Finally, a comparison was made between the combined categories of the sensitive zone of 1973 and forest density classes of 2010 with forest cover density of 1973, to quantify the area under each sensitive zone of 1973 in combination with a density class of 2010 belongs to the area of same density class in 1973 (Fig. 4).

3 Results

Comparison of vegetation density between 1973 and 2010 shows a significant decrease in the area of very dense forest (2.4 km^2) in 2010. Of the total area covered by natural vegetation (321 km^2) the moderately dense and very dense forests together occupied an area of 20.9% in 2010 whereas in 1973, it was 22.2%. Open forest (deciduous forest), which is the major vegetation type of Mudumalai covered 19950 ha in 2010. The area under open forest has shown a significant increase of about 1545 ha between 1973 and 2010. However, the other forest cover classes showed a decreasing trend between 1973 and 2010 (Table 1).

Table 1 Change detection in the vegetation density between 1973 and 2010.

Vegetation Type	Area in 1973 (ha)	Area in 2010 (ha)	Change in Area (ha)
Non forest	361.08	21.13	-339.94
Scrub forest	6249.24	5414.27	-834.96
Open forest	18405.44	19950.62	1545.189
Moderately dense Forest	4481.33	4289.26	-192.06
Very dense forest	2670.48	2442.60	-227.87

Negative values indicate decrease in area; Positive values indicate increase in area.

The results of weighted overlay analysis show that the different forest areas of Mudumalai which are prone to degradation are at different risk levels. In 2010, about 47.36% of the forest area (15212 ha) was under a low risk category, which includes the forests that are situated far away from the human settlements, with no accessibility to nearby roads, river systems and pilgrim sites. The medium risk zones occupied an area of about 7981 ha (24.84%) of the total forest cover in 2010 whereas it was 3915 ha (12.17%) in 1973. The high risk zone has observed large-scale changes in forest cover between 1973 and 2010, and the change in area is about 1567 hectares (Table 2). The occurrence of a high risk zone was mainly around the settlement area.

Table 2 Change detection in the area of sensitive zones of 1973 and 2010.

Class	1973		2010	
	Area (ha)	Area (%)	Area (ha)	Area (%)
No risk zone	15494	48.17	6409	19.95
Low risk zone	11804	36.70	15212	47.36
Medium risk zone	3915	12.17	7981	24.84
High risk zone	950	2.95	2517	7.83

The degrees of sensitive areas are classified into four categories namely: no risk zone, low risk zone, medium risk zone and high risk zone (Fig. 5a and 5b).

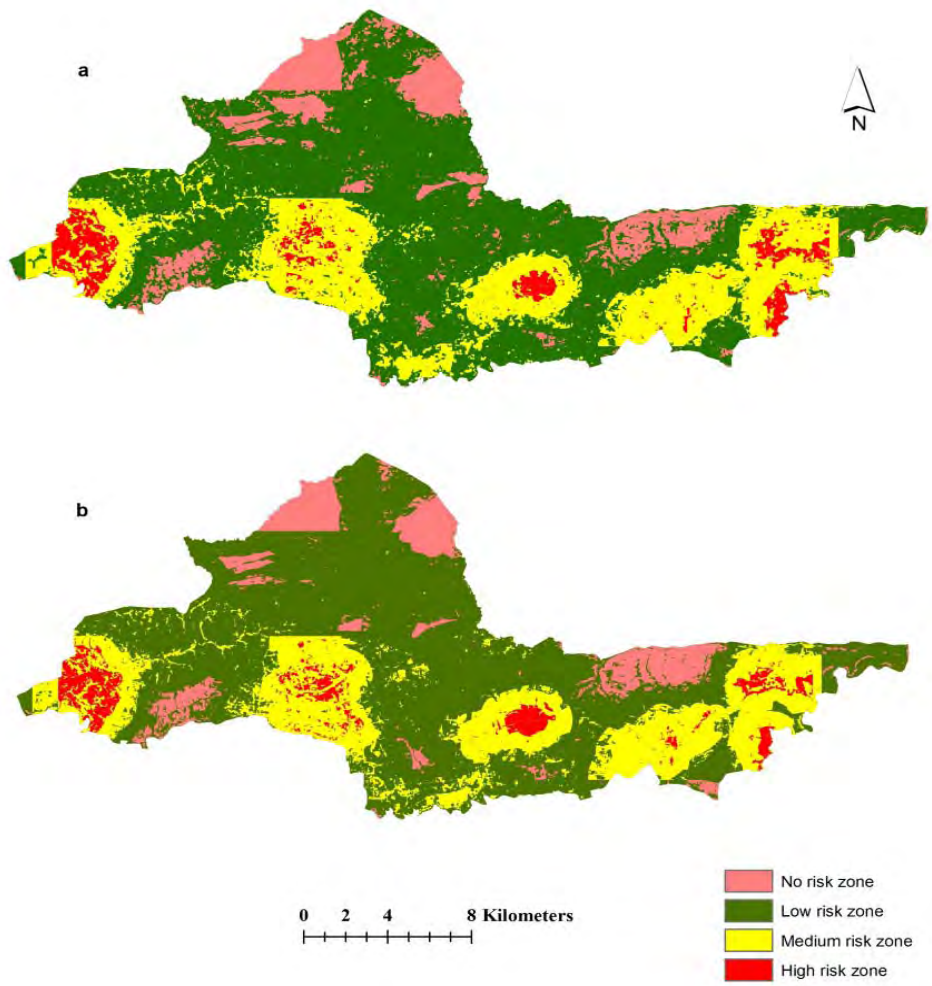

Fig. 5 a. Sensitive zone map of 1973; b. Sensitive zone map of 2010.

Change detection analysis was performed between the risk zones of 1973 and the vegetation density of 2010 (Table 3). It was observed that medium and high risk zones were distributed mainly in the open forest region (4177.45 and 523.63 ha respectively). Secondly, about 24% of a high risk zone was present in very dense forest.

Table 3 Change matrix between sensitive zones in 1973 and vegetation density in 2010.

Area of Sensitive zone in 1973	**Area of NDVI in 2010 (ha)**				
	Non forest	**Scrub forest**	**Open forest**	**Moderately dense forest**	**Very dense forest**
No risk zone	0.85	715.95	979.82	262.58	109.31
Low risk zone	0.04	2281.03	14325.7	1971.64	869.93
Medium risk zone	0.02	2120.89	4177.45	1787.76	1057.29
High risk zone	0.05	267.5	523.63	333.43	374.49

According to 1973 risk zonation, though the area under scrub forest in 1973 was 96.91 ha that has increased to 267.5 ha in 2010. Similarly, the open forest in 1973 has 277 ha under high risk zone has increased to 523.63 ha in 2010 (Table 4). These increases in the areas from 1973 to 2010 and this change may be due to the expansion of the agricultural lands and usage of footpaths and roads for the firewood collection and cattle grazing.

Table 4 Change detection between sensitive zones and vegetation density class.

Degradation Prone zone	**Area of forest density in 2010 (ha)**		**Area of forest density in 1973 (ha)**	
	Scrub	**Open**	**Scrub**	**Open**
High risk zone	267.5	523.63	96.91	277.48
Medium risk zone	2120.89	4177.45	974.74	2561.52

The current study deviates from all other prioritization study in the following aspects: a) in this study, two sensitive zonation maps were prepared for two time periods, 1973 and 2010. b) the sensitive zonation map prepared for 1973 was compared with the forest cover map of 2010 and the area under different sensitive zonation, and their corresponding present density classes were assessed. c) The combinations of sensitive zonation in 1973, and their corresponding forest cover class in 2010 were once again compared with the forest cover class of 1973, to bring out the contribution of area by various forest cover density classes in 1973 to the degraded forest in 2010, which belong to highly risk category. d) A comparison of 1973 and 2010 risk zonation alone reveals that the area under no risk zone has drastically decreased and medium and high-risk zone has considerably increased.

4 Conclusion

This study investigated the mapping of sensitive zones using remote sensing and the weighted overlay model in Mudumalai Tiger Reserve. We parameterized the weighted overlay model to analyze the whether the sensitive zones of the forest are degraded from 1973-2010. The rates and driving factors of forest changes were identified using remote sensing data. Then, these data were used to calculate the area of risk zones and vegetation density. The identification of the areas vulnerable to forest changes is fundamental in the Mudumalai and has important implications for biodiversity conservation in the region. One of the most important applications would be to relate the spatial patterns of forest changes to the spatial distribution of species. The loss of the forest is mainly near the settlement area which threatens the survival of many species in this region. In particular, cultivation within forest around the settlements areas drastically altered the composition and abundance of plant species and the conversion of forest into cropland indicates increasing pressure on the steep land areas in the surrounding areas. From a protected area management perspective, the risk zone and vegetation density maps of Mudumalai can help protected area managers identify where conservation and forest management efforts should be focused. The monitoring process can be implemented by regularly updating satellite derived maps of vegetation density and predicting forest change patterns. Moreover, these sensitive maps can be used to focus biological conservation efforts.

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