ASSESSMENT OF THREATS TO FOREST ECOSYSTEMS USING GEOSPATIAL TECHNOLOGY IN JHARKHAND STATE OF INDIA

An integrated approach was adopted to evaluate the three threats that are a forest fire, deforestation and forest fragmentation using remote sensing and GIS data with a synergistic approach for spatial assessment and analysis.

by Firoz Ahmad and Laxmi Goparaju

The study has attempted to generate the spatial information of three forest ecosystem degradation indicators viz. deforestation, forest fragmentation and forest fires using a systematic conceptual approach in the Jharkhand state of India.

Conservation of forest biodiversity is vital for mankind as it provides enormous benefits such as biological resources and ecosystem services. Of late, the forests are facing risk and threats such as fragmentation, degradation and forest fires which are responsible for the deteriorating condition.

The progress in the field of science and technology like satellite remote sensing and GIS since the past few decades in India and the world provide an opportunity to track and monitor the changes taking place on the Earth's surface. Besides, analysis of large spatial data in GIS can also provide insight into the various driving factors which lead to the loss of biodiversity in the threatened ecosystems i.e forests.

The present study has attempted to generate the spatial information of three forest ecosystem degradation indicators viz. deforestation, forest fragmentation and forest fires using a systematic conceptual approach in the Jharkhand state of India. The satellite remote sensing data sets belonging to Landsat were used to analyze the forest cover of Jharkhand state.

To identify the areas of threat, grid cells (5KmX5Km) were generated in GIS domain. The deforestation was

About Author

Laxmi Goparaju

Scientific Adviser
Vindhyan Ecology and Natural History Foundation,
Mirzapur, Uttar Pradesh India
Email: *goparajulaxmi@yahoo.com*

Feroz Ahmad

Scientific Adviser
Vindhyan Ecology and Natural History Foundation,
Mirzapur, Uttar Pradesh India
Email: *adfiroz@yahoo.com*

assessed using multi-source data of 1935 and 2015. Historical evaluation of deforestation reveals that the major changes had occurred in a forest of Jharkhand and identified 1224 extinct, 248 critically endangered, 318 endangered and 396 vulnerable ecosystem grid cells. The fragmentation analysis has identified 148 critically endangered, 296 endangered and 402 vulnerable ecosystem grid cells. Forest fire point's data from the year 2005 to 2016 were utilized and analysis was done. A further frequency of forest fires in each grid was noted. The result indicates that 67.3% of grid cell of Jharkhand forest was affected with a forest fire. Conservation status has been evaluated based on the value of threat of each grid which was the basis for conservation priority hotspot. About 2.1% of Jharkhand forest ecosystem grids had extremely high ecosystem risk stage and had been included under the category of conservation priority hotspot-1 followed by 19.7% conservation priority hotspot-2, 41.3% conservation priority hotspot-3, 27.8% conservation priority hotspot-4, and 9.1% lowest conservation priority hotspot-5. This study highlights the ability to integrate remote sensing and GIS data for mapping the forest degradation, which can be useful in formulating the strategies and policies for protection and conservation of forests.

Introduction

The conservation of forests has become a major concern with the international community ever since the Convention on Biological Diversity (CBD) was drafted in Rio in 1992. Forests and woodlands cover nearly 40 percent of the Earth's land surface, and they are the most biologically diverse ecosystems in most parts of the world (WRI-IUCN-UNEP, 1992). Forests are the single most important banks of global biodiversity (Kapos and Iremonger, 1998). Tropical dry deciduous forests are one of the largely neglected natural resources all over the world. They are the most poorly protected forest categories in the world with only 5% of the area under protection (WCMC, 1996) as cited by Kapos and Iremonger (1998). However, these forests serve the local, tribal communities by meeting their needs for food, fuelwood, fodder, fiber and a range of subsistence products besides performing other functions such as the protection of watersheds, providing opportunities for tribal people, ecotourism and habitats for wildlife.

Forest fragmentation, deforestation, forest fire may negatively influence the forest of its original biodiversity at the levels of genes, species, and communities. The loss of biodiversity was reported by increasing forest fragmentation (Jha et al., 2005). Thus, it is important to evaluate the threats to biodiversity conservation (Reddy et al., 2014). Ancient forest species are important and crucial in terms of nature conservation because they integrate both qualitative (forest quality) and quantitative (diversity) conservation criteria (Peterken 1996). Habitat fragmentation is the process that occurs when a habitat or land cover type is subdivided either by a natural disturbance (e.g. fire or storm) or by human activities e.g. roads or cultivation (Dale and Pearson, 1997). The threats posed by forest disappearance and fragmentation to local biodiversity have been well recognized for nearly two (few) decades (Harris, 1984). Although spatial heterogeneity is a natural phenomenon, human activities are altering the natural landscapes by changing the abundance and spatial pattern of habitats. The two most significant effects of forest fragmentation are a decrease in population sizes and reduction of species diversity (Goparaju et al., 2005; Goparaju and Jha, 2010).

Deforestation implies clearing the forest cover by falling trees or removing the plantations to make way for agricultural, infrastructure and development purposes. A permanent loss of forest cover occurs which cannot be restored to a forest again. According to FAO, it is estimated that the loss in forest cover per year is 18 million acres (7.3 million hectares) - *(http://www.conserve-energy-future.com/various-deforestation-facts.php)*

Removal of trees causes imbalance in the ecosystem and in the long run will affect the environment also. Another major factor which causes loss of trees is forest fire in various parts of the world. It occurs mainly due to the warm summers and mild winters. They may be natural or human-induced but, in both cases, cause large damage to the forest ecosystem. Both the above factors are responsible for increase of carbon in the atmosphere thus causing global climate change. The biogeochemical cycles are altered by deforestation (Potter, 1999).

The World Conservation Strategy (IUCN, 1980) quoted by (McNeely et al.,1990), defines conservation as the management of human use of the biosphere in such a way that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of the future generation. Since biodiversity is so closely linked with human day today needs, its conservation should rightfully be considered as an element of national security (WRI, IUCN and UNEP 1992). Conservation of biodiversity requires management of entire landscapes, not just protection of individual reserves (Noss, 1990). Core areas managed for the protection of biodiversity could form the backbone for any regional land conservation system surrounded by buffer zones where compatible human uses could be partially allowed.

RS & GIS applications in Forest Conservation Planning

Remote sensing data facilitate as a source of rapid acquisition of any land use information coupled with ground truth of low cost (Pal and

Mather, 2004). In this regard, the Landsat satellite data has been successfully employed for various research activities since 1972 which is the year of its launch. This remote sensing satellite data has a medium spatial resolution and covers worldwide (Hansen and Loveland, 2012). When such data is analysed in GIS (Geographic Information Tool) many of the ecosystems could be studied spatially and temporally (Ahmad and Goparjau, 2017a, b). Some of them were used to study the changing levels of biodiversity with respect to changing forest fragment size (Goparaju et al., 2005). Further it has been utilized for inventorying, monitoring and assessing the terrestrial biodiversity at regional (Shi and Singh, 2002); landscape (Roy and Behera, 2002) level. Besides, it can employ to identify gaps in the protection network which is a GIS-based method (Scott et al., 1993). In a gap analysis of Western Ghats in India, Ramesh et al., 1997; Jha et al., 2000 found that several areas of high biodiversity were excluded from the highest levels of protection.

Few pieces of research have addressed the issue of evaluating the threats and determining the conservation priority hotspot. Reddy et al., 2014 have evaluated the forest ecosystem of the Orissa state of India using the five threats viz. deforestation, forest degradation, fragmentation index, forest fire risk map, and invasive species abundance. The study used 5kmX 5km grid. Further, by integrating various threats by providing equal weights to all, conservation priority hotspot was achieved. A similar study was conducted by Reddy et al., 2015 who have evaluated the forest ecosystem of Telangana state of India using three threats viz. deforestation, fragmentation index and forest fire risk map. Kanga and Singh 2017 studied the forest fire in the Taradevi forest of Himachal Pradesh (India). The study analyzes the forest fire spread analysis and loss assessment using simulation modeling techniques using FARISTE. Findings of the study are helpful in the development of forest fire management and planning.

Apart from Orissa and Telangana states of India, such studies have not been conducted for any other state of India thus this is potential research gap at the state level. The present study has been conducted in the Jharkhand state. It is a land of forest and tribal. A symbiotic relationship persists between the tribals and the forests (Dungdung, 2015). Of late, the forest is threatened due to human and anthropogenic activities, which has deteriorated the condition of forests as well as threatened the livelihood of the tribal people who are mainly dependent on them. The forests have not only witnessed the degradation in forest quality but also in quantity in the recent past. The problem regarding food and livelihood insecurity has escalated due to deforestation. It has further accelerated the displacement, migration and breaking away from the natural environment, also social ambiguity among the tribals.

The present study has attempted to prepare a spatial database for the state of Jharkhand, India to assess the value or quality of the status of the forest ecosystems and identify conservation priority hotspots. In this regard, an integrated approach was adopted to evaluate the three threats that are a forest fire, deforestation and forest fragmentation using remote sensing and GIS data with a synergistic approach for spatial assessment and analysis.

The Study Area

The geographical coordinates of the study area of Jharkhand comprise of latitude 21 ° 58' 02'' N to 25 ° 08' 32''N and longitude 83° 19' 05''E to 87° 55' 03 '' E, whereas total geographical area is 79,714 km² accounted for nearly 2.4 % of total geographical area of the country (Figure 1).

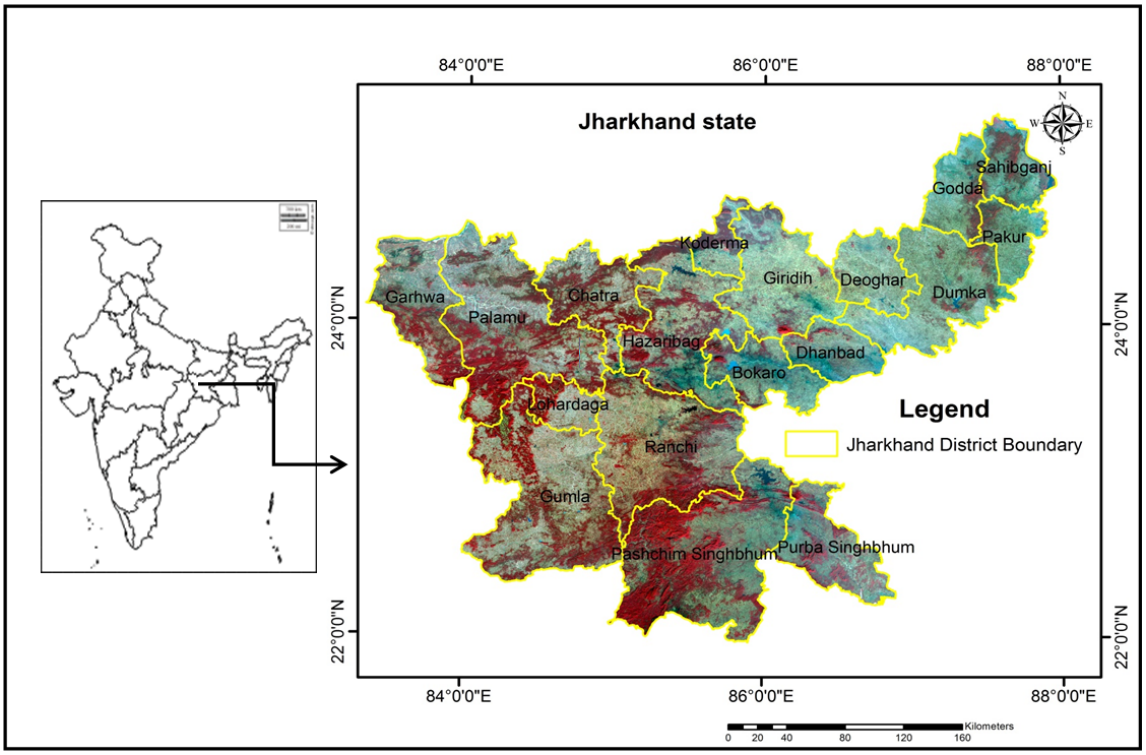

Figure 1. The location of the study area.

The word 'Jharkhand' implies as an 'area of land mass covered with forests'. The state is a home to 30 different tribal groups. Some of the aboriginal races are Santhals, Mundas, Oraons, Hos, Kharia, Bhumij, Birhors, etc. They have a close association with nature. They are commonly known as "adivasis" which means that they are the original settlers of the land. Their livelihood revolves around these forests. They begin their day by collecting edible fruits, roots, flowers, mushroom, tubers, wild vegetables, honey, birds, animals, fuelwood etc. for their daily requirement. Medicinal herbs, fruits, grasses, and leaves etc. serve the purpose of curing diseases and common ailments. Besides, they also preserve the sacred groove in the vicinity of the forest known as Sarna. The forests of this region are tropical dry deciduous with elevation varies from 6 m to 1366 m from the mean sea level. Jharkhand average moderate rainfall varies from 945 mm to 1297 mm with a temperature variation of 6°C in winter to 47°C in summer.

Materials and Methods

- **Data Preprocessing and Analysis**

The identified indicators viz. deforestation, fragmentation, forest fires have been used for the assessment of threatened forest ecosystem in Jharkhand. The flowchart describing the methodology has been furnished in Figure 2. The geospatial evaluation for the threats in forest ecosystem in Jharkhand was analysed using various criteria which are briefly described in Table 1. The forests in the present case have been defined as the area of land with more than 1% of grid area dominated with indigenous tree species with overstory canopy greater than 10%. In order to comprehend the condition of threats, a grid of 5 km × 5 km (each 25 km2) size has been prepared. Historical/long-term changes of forest cover have been expressed in quantitative terms. Only the terminology recommended by IUCN for Red list status of species has been used for the ecosystems, but the criteria for each category of threatened ecosystem has been developed by Reddy et al., (2014) which is used for this study. Forest ecosystems are considered as Least Concern/low risk if no threat identified as per the selected parameters.

- **Processing of the Satellite Data**

The software used was ERDAS IMAGINE 11 for digital image processing and ArcGIS for GRID analyses and presenting the results in the geospatial domain. The nine Landsat images (Table 1) of the time period December 2015 were downloaded from USGS website. The data were mosaicked and resampled using nearest neighbord resampling method in order to preserve the radiometry and spectral information in the imagery. For classification, we have used hybrid classification techniques (combination of visual, Supervised and Normalized Difference Vegetation Index) to map the forest cover with two classes viz. forest and non-forest class. In order to remove the noise and to smoothen the classified image, a 3X3 filter was executed. To evaluate the accuracy of the forest cover map, around 250 random sampling points were generated. They were assigned to the respective classes after confirming them against ground truth data and literature sources. Overall accuracy and Kappa statistic were computed using the error matrix.

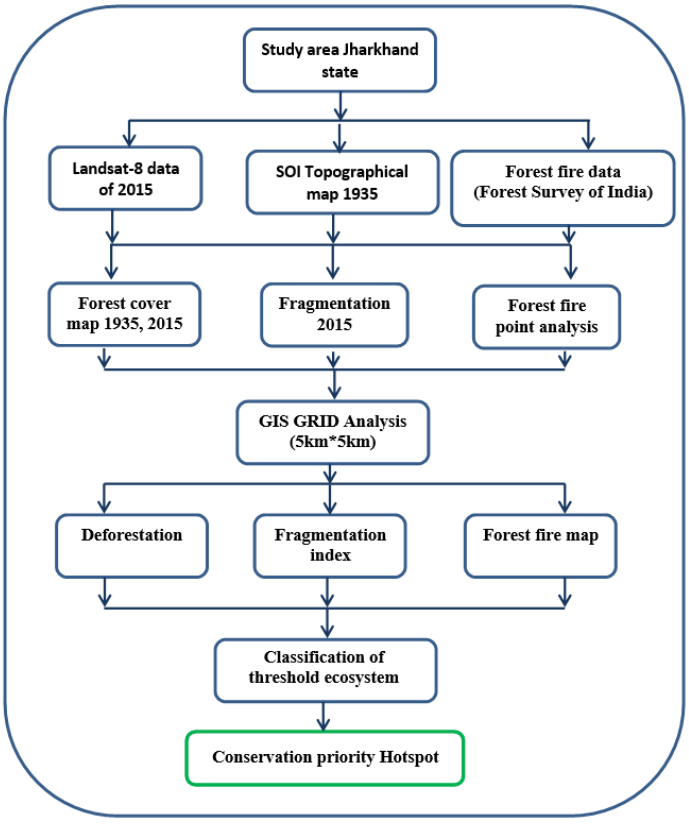

Figure 2. Flow chart showing the methodology adopted.

Satellite	Sensor	Path/ Row	Dates
Landsat 8	OLI_TIRS	142/43	01-12-2015
Landsat 8	OLI_TIRS	141/43 141/44	26-12-2015 26-12-2015
Landsat 8	OLI_TIRS	140/43 140/44 140/45	19-12-2015 19-12-2015 19-12-2015
Landsat 8	OLI_TIRS	139/43 139/44 139/45	28-12-2015 28-12-2015 28-12-2015

Table1. Satellite data details.

- **Threatened Forest Ecosystem Indicator**

1. Deforestation: The spatial distribution of forest cover during the last 80 years has been mapped. Survey of India topographical maps of 1924–1935 (say 1935) were downloaded from - *http://www.lib.utexas.edu/maps/ams/india/* and interpreted visually to generate spatial data on 1:250,000 scale. Remote Sensing data pertaining to Landsat 8 (2015) was used to see the changes with respect to the year 1935. The change in land cover with depletion of tree crown cover to less than 10% was considered as deforestation following the

definition of FAO (FAO, 2011).

On comparing the spatial data on forests in the time series 1935–2015 the forest cover change for the period of 1935–2015 has been considered for assessment of the historical decline wherein if the reduction in geographical distribution of forest cover exceeds >90% considered as Critically Endangered, >70% as Endangered and >50% as Vulnerable (Keith et al., 2013). In long-term decline, if the reduction in the geographical distribution of forest cover exceeds >80% considered as Critically Endangered, >50% as Endangered and >30% as Vulnerable (Keith et al., 2013). In our study we have used the criteria for identification of threatened forest ecosystem based on deforestation were based on a reduction in forest cover exceeds >80% considered as Critically Endangered, >50% as Endangered, >30% as Vulnerable, >10% as near threatened and <10% as least concern.

The analysis of the results has taken these three main points into consideration: firstly, grid cell size of 5 km × 5 km was taken for assessment of threatened ecosystems; secondly, as the analysis was based on multi-time frame data (1935–2015) there is a change in number and distribution of threatened ecosystems, thirdly, the assessment was carried out on 1:250,000 scale.

2. Fragmentation

Habitat fragmentation can be simply characterized as a break up of a continuous landscape containing large patches into smaller, usually more numerous and less-connected patches. In the present study, analysis of fragmentation has been quantified using geospatial analysis in terms of a number of patches of forest and non-forest per unit area. The number of forest patch per unit grid was evaluated based on the forest cover map prepared for the year 2015, it was converted to a vector which was used for spatial grid wise analysis. The criteria for recognization of the threatened forest ecosystem is based on fragmentation were identified by a number of forest fragmented patch. The forest fragmentation index > 70% as critical endangered, > 50% as endangered, > 40% as vulnerable, > 30% as near threatened and < 30% as least concern.

3. Forest Fires

To analyze the forest fires analysis in the state of Jharkhand, the forest fire data was downloaded from Forest Survey of India - *http://fsi.nic.in/forest-fire.php* from 2005 to 2016. The forest fire point file downloaded was in MS-EXCEL file with latitude and longitude. It was exported into shape file year wise using ARC/ GIS Software. The number of forest fires per unit grid was evaluated based on decadal forest fire data. The criteria for identification of forest fire ecosystem were based on number of forest fires. The number of fires >21 as critical endangered, 20-12 as endangered, 11-6 as vulnerable, 5-1 as near threatened and 0 as least concern.

- ***Conservation Priority Hotspots***

The analysis so far has considered as a single potential threat factor. Here, we focus on threatened forest ecosystems which are facing multiple threats like deforestation, fire, and fragmentation rather than single threat factor, as the most prominent, readily useful and identifiable zones for high conservation priority. Conservation status of ecosystems is recorded based on numbers 1–5 are given depending on values of category from deforestation, fragmentation and forest fires. These factors carry equal weight so that they can be combined into various levels of conservation ranking and classified into five categories. Conservation priority hotspot-1 has the highest threat value based on evaluation was in the range of 12–13 followed by conservation priority hotspot-2 with threat value of 10–11, conservation priority hotspot-3 with threat value of 8–9, conservation priority hotspot-4 with threat value of 6–7, conservation priority hotspot-5 with threat value of 3–5.

Results

- **Deforestation**

A comparative evaluation revealed that major changes in forest cover occurred during 1935–2015 (Table 2 and Figure 3). Based on this, the study identified 1224 extinct, 248 Critically Endangered, 318 Endangered, 396 Vulnerable, 284 nearly threatened and 126 least concern ecosystems. Most of the least concern ecosystem is in the middle of the forest surrounded by less dense forest highly inaccessible due to complexity of terrain and mostly away from population. The driving factors of deforestation between the period 1935 and 2015 were industrialization, urbanization, mining activity and conversion of forest land to other land use purpose viz. dam construction, agriculture purpose etc. Within the state, the losses of forest ecosystems are more pronounced in those areas where population was high resulted into forest loss by various their anthropogenic activity. The overall classification accuracy of the forest cover map of 2015 was 94.1%. The Kappa statistic value was 0.91. Validation of maps for 1935 was done based on forest cover map of 2015.

- **Fragmentation**

The geospatial analysis has identified a pattern of fragmentation across the state of Jharkhand. Based on this, the study identified 148 grids under high fragmentation index and categorized as Critically Endangered, followed by 296 Endangered, 402 Vulnerable, 296 nearly threatened and 230 least concern ecosystems (Table 2 and Figure 4). The severe forest fragmentation was found in

southern part of Ranchi, the eastern part of Garhwa, the western part of Palamu and southern part of Gumla district require immediate conservation efforts in order to arrest further deterioration due to land use practices.

- **Forest Fires**

The average of 12 years (2005-2016) indicates Jharkhand face 452 number of forest fire every year. In the year 2010, the forest fire frequency was roughly 3 times higher with the annual average, the same year was also declared as drought year - *http://nidm.gov.in/PDF/DP/JHARKHAND.pdf*. The forest fire analysis reveals the very high identified 27 grids is under high forest fire impact and categorized as Critically Endangered, followed by 85 Endangered,184 Vulnerable, 628 nearly threatened and 448 least concern ecosystems (Figure 5). Study reveals 67.3% of grid cell of Jharkhand forest was affected with fire. Very highly forest fire grid falls in South of Jharkhand (Pachim Singhbhum district area), North west of Jharkhand (south of Palamu and Garhwa district area) and Northeast of Jharkhand (at the junction of Pakur, Sahabganj and Godda district area). The Paschim Singhbhum and Palamu district together roughly receive 50 % of the annual forest fire. Therefore, immediate conservation efforts are required in severe forest fire grids of Paschim Singhbhum and Palamu district to arrest further deterioration.

- **Conservation Priority Hotspots**

This analysis complements an assessment of the threatened ecosystems undergoing multiple threats. The high conservation priority in threatened ecosystem is considered as hotspot-1, followed by hotspot-2, hotspot-3, hotspot-4 and lowest conservation priority is for hotspot-5. 2.1% (29 grids) of existing forest had severe ecosystem level risk and included under the category

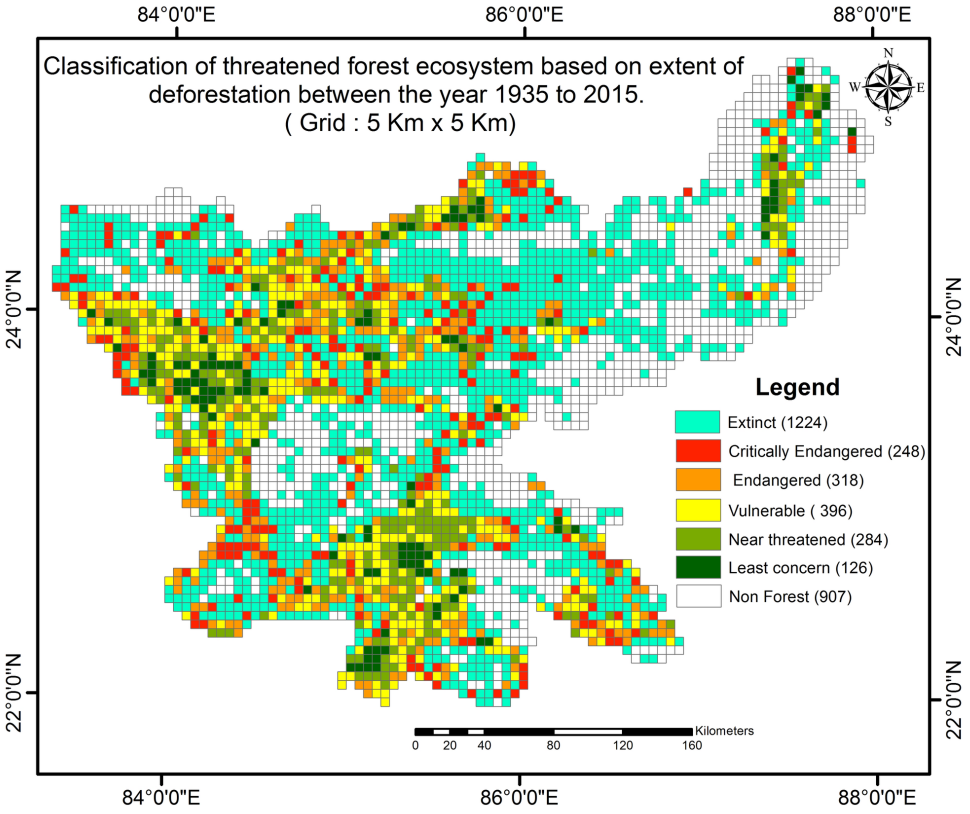

Figure 3. Classification of threatened forest ecosystem based on extent of deforestation.

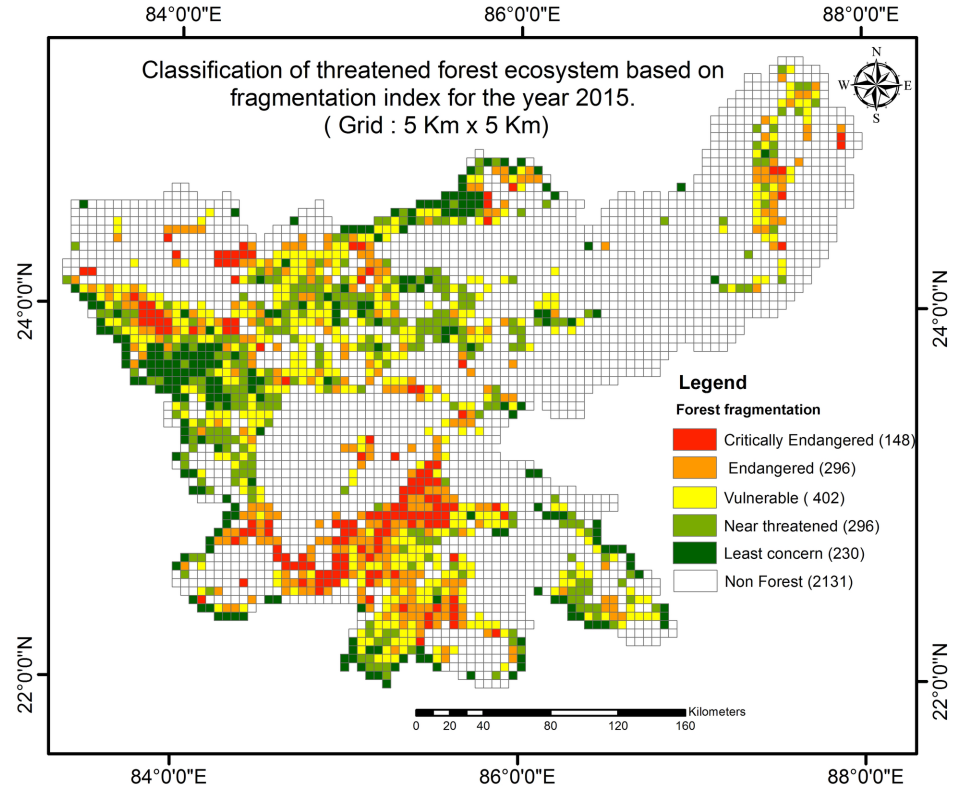

Figure 4. Classification of threatened forest ecosystem based on fragmentation index.

of conservation priority hotspot-1, followed by 19.7% (270 grids) in conservation priority hotspot-2, 41.3% (566 grids) in conservation priority hotspot-3, 27.8 % (382 grids) in conservation priority hotspot-4 and 9.1% (125 grids) in conservation priority hotspot-5, (Figure 6). The majority of conservation priority hotspot-1 mostly falls in West Singhbhum, Ranchi, Palamu and Garhwa district.

The similar study in the state of Orissa and Telangana have also indicated considerable loss of biodiversity at an ecosystem level. The analysis has identified 5.8% (326 grids) of existing forest of Orissa had severe ecosystem level risk and placed under conservation priority hotspot-1 (Reddy et al 2014) whereas the similar study in existing forest of Telangana state identified 2.1% (39 grids) of had severe ecosystem level risk and placed under conservation priority hotspot-I (Reddy et al 2015)

The regions of greater risk have been prioritized since the risk of local extinction is likely to be increased for many species. Thus, understanding the conservation priority hotspots helps directly in conservation programs of forest ecosystems.

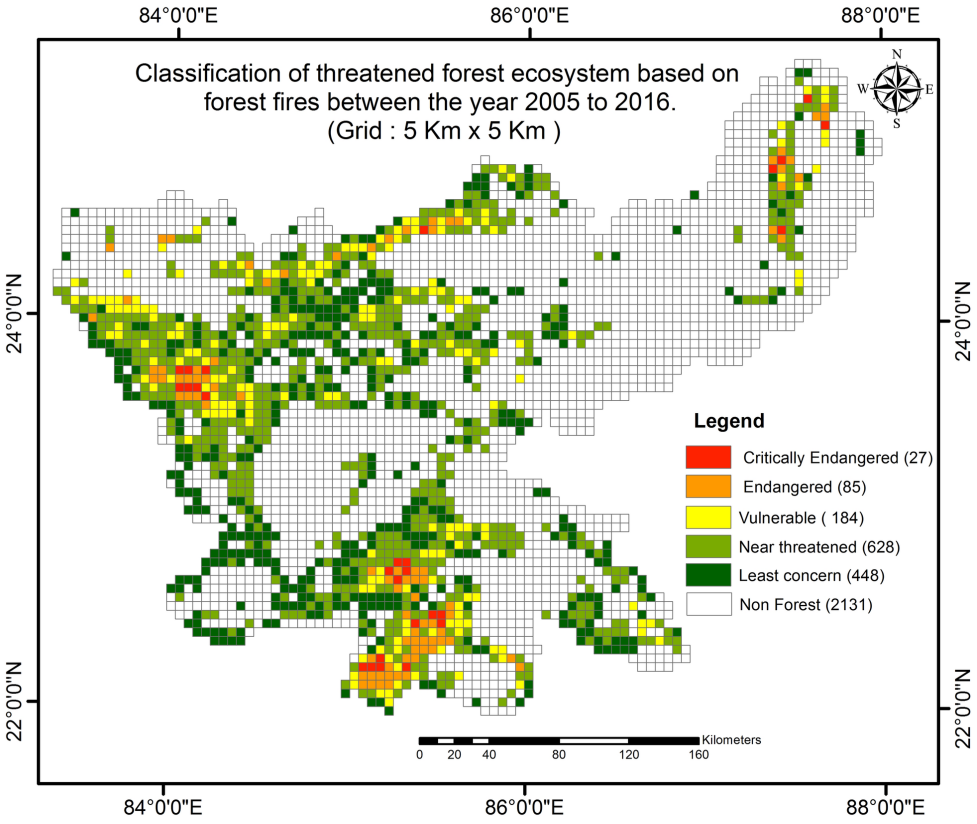

Figure 5. Classification of threatened forest ecosystem based on forest fire.

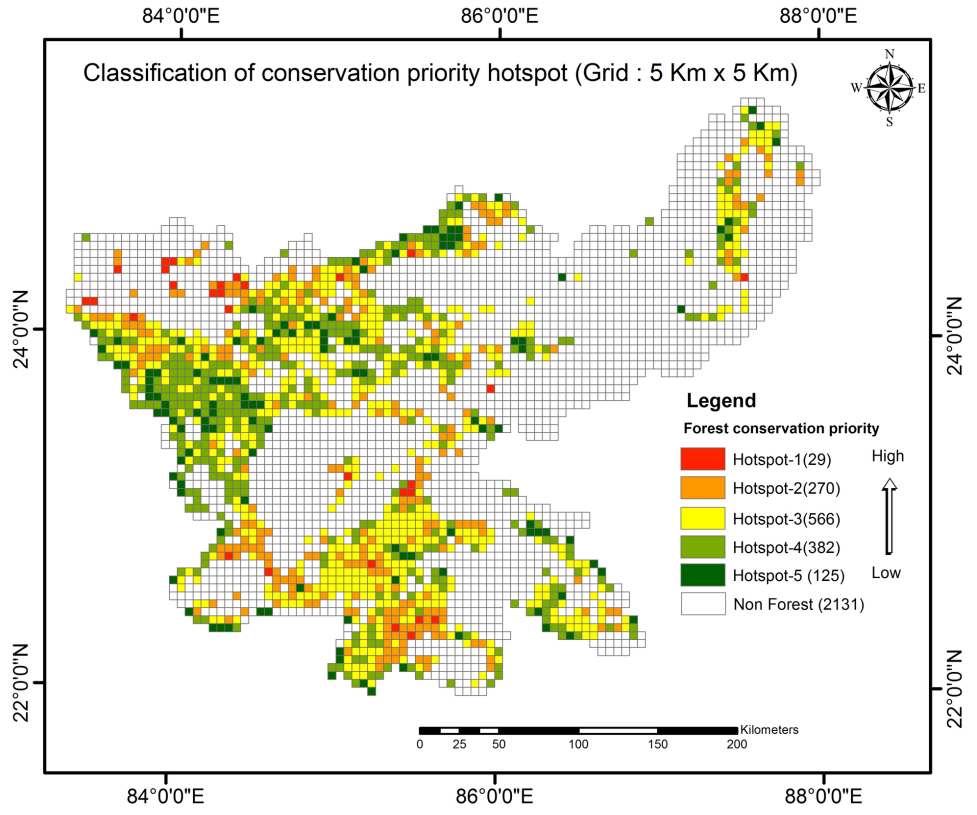

Figure 6. Classification of conservation priority hotspot.

Discussion

The present study has attempted to develop multiple grid-based maps depicting the various threatened categories which are based on ecosystem degradation drivers such as deforestation, fragmentation and forest fire. Such an approach of spatial analysis identifies all the forest ecosystems threats under various categories. They are responsible for the degradation of forests within the state which is a home to the tribes and supports a large number of flora and fauna. Hence, there is an urgent need to formulate the conservation measures and strategies along with

environmental education and people participation which would involve local bodies to manage biodiversity in conservation priority hotspots. It is recommended that an immediate and suitable conservation action plan for the identified hotspots of study area be implemented.

Systematic forest restoration activities are required in conservation priority hotspots-1 followed by conservation priority hotspots-2 and conservation priority hotspots-3. Jharkhand has witnessed severe forest fire in the past and the year 2010 was the worst. In the year 2017 only within 5 days (from 1st April to 5th April) 441 forest fires were recorded in Jharkhand by the Forest Survey of India (FSI). There is a need to formulate the forest fire policies at state and country level to safeguard the forests. Infrastructure development which bifurcates the forests should be discouraged.

Ecosystem	Deforestation		Fragmentation		Forest fire	
	No. of grids	% of grids	No. of grids	% of grids	No. of grids	% of grids
Extinct	1224	34.9				
Critically Endangered	248	7.1	148	4.2	27	0.8
Endangered	318	9.1	296	8.4	85	2.4
Vulnerable	396	11.3	402	11.5	184	5.3
Near Threatened	284	8.1	296	8.4	628	17.9
Least Concern	126	3.6	230	6.6	448	12.8
Non-forest	907	25.9	2131	60.8	2131	60.8
Total	3503	100	3503	100	3503	100

Table 2. Analysis of threatened forest ecosystems based on deforestation, fragmentation and fire.

Authors' Contribution

FA proposed the idea and analyzed the satellite and ancillary data in GIS domain and drafted the manuscript, LG supervised the analysis and improved the manuscript. All authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests.

Funding

No funding in any form has been received by any of the authors for current work.

Acknowledgments

The authors are grateful to the USGS for a free download of Landsat data and Forest Survey of India for free downloads of the forest fire data. Required GIS layers were downloaded from DIVA GIS.

The original paper, which was published in Current World Environment "Ahmad F, Goparaju L. Assessment of Threats to Forest Ecosystems Using Geospatial Technology in Jharkhand State of India. Curr World Environ 2017;12(2). DOI: http://dx.doi.org/10.12944/CWE.12.2.19"

References

1. WRI-IUCN-UNEP. Global Biodiversity Strategy: Guidelines for Action to Save, Study, and Use Earth's Biotic Wealth Sustainably and Equitably. World Resource Institute, Washington, D.C. (1992)

2. Kapos, V., & Iremonger, S.F., Achieving Global and Regional Perspectives on Forest Biodiversity and Conservation. In: Assessment of Biodiversity for improved Forest Planning. Proceedings of the conference on Assessment of Biodiversity for improved Planning, 7-11 October 1996, Monte Verita, Switzerland. (eds.). P. Bachmann, M. Kohl, and R. Paivenen. Kluwer Academic Publishers, London. pp 3-13. (1998)

3. WCMC, World Conservation Monitoring Centre. Global Biodiversity: Status of the Earth's Living Resources. Chapman and Hall, London. (1992)

4. Jha, C.S., Goparaju, L., Tripathi, A., Gharai, B., Raghubanshi, A.S., & Singh, J.S., Forest fragmentation and its impact on species diversity: an analysis using remote sensing and GIS. Biodiversity and Conservation 14(7): 1681–1698. (2005)

5. Reddy, C. S., Khuroo, A. A., Harikrishna, P., Saranya, K. R. L., Jha, C. S., & Dadhwal, V. K., Threat evaluation for biodiversity conservation of forest ecosystems using geospatial techniques: a case study of Odisha, India. Ecological Engineering, 69: 287–303. (2014)

6. Peterken, G.F., Natural Woodland: Ecology and Conservation in Northern Temperate Regions. Cambridge University Press, Cambridge. (1996)

7. Dale, V.H., & Pearson, S.M., Quantifying Habitat Fragmentation due to Land use change in Amazonia. In: Tropical Forest Remnants: ecology, management and conservation of fragmented communities. (eds.). W.F. Laurance., and R.O. Bierregaard, Jr. University of Chicago Press, Chicago, USA. pp 400-409. (1997)

8. Harris, L.D., The fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity. University of Chicago Press, Chicago. (1984)

9. Goparaju L., Tripathi A.,& Jha C.S., Forest fragmentation impacts on phytodiversity – An analysis using remote sensing and GIS, Current Science 88: 1264-1274. (2005)

10. Goparaju L. & Jha C.S., Spatial analysis of plant communities in fragmented forest of dry tropics in Vindhyan highlands using remote sensing and GIS, International Journal of Tropical Ecology 51(1): 55-65.(2010)

11. Potter,S.C., Terrestrial biomass and the effects of deforestation on the global carbon cycle results from a model of primary production using satellite observation. Bioscience 49, 769–778.(1999)

12. MacArthur, R.H.,& Wilson, E.O., The theory of island biogeography. Princeton University Press. Princeton, NJ. (1967)

13. McNeely, J.A., Miller, K.R., Reid, W.V., Mittermeier, R.A., & Werner. T.B., Conserving the World's Biological Diversity. Gland, Switzerland: and Washington, D.C.: IUCN, WRI, CI, WWF-US, and the World Bank. (1990)

14. Noss, R.F., Indicators for monitoring Biodiversity: A Hierarchical Approach. Conservation Biology 4(4): 355-364. (1990)

15. Pal, M., Mather, P.M., Assessment of the effectiveness of support vector machines for hyperspectral data. Future Gener. Comput. Syst. 20, 1215–1225. (2004)

16. Hansen, M.C.,& Loveland, T.R., A review of large are monitoring of land cover change using Landsat data. Remote Sens. Environ.122, 66–74. (2012)

17. Ahmad, F., & Goparaju, L., Geospatial Assessment of Forest Fires in Jharkhand (India) Indian Journal of Science and Technology. 10(21): DOI: 10.17485/ijst/2017/v10i21/113215 (2017a)

18. Ahmad, F. & Goparaju, L., Long term deforestation assessment in Jharkhand state, India: A grid based geospatial approach. Biological Forum 9(1):183-188. (2017b)