GEOSPATIAL APPROACH FOR FOREST COVER CHANGE AND VULNERABILITY ANALYSIS THROUGH MULTI CRITERIA EVALUATION IN KALLAR WATERSHED, PART OF NILGIRI BIOSPHERE RESERVE

Rahaman S. Abdul *, Aruchamy S., ** Jegankumar R.*

Department of Geography, Bharathidasan University, Tiruchirappalli, Tamil Nadu

Abstract

Degradation of forest decreases the tree cover, the biodiversity in the forest and results in the changes to a lower state of the forest structure. Continued degradation of the forests can lead to the destruction of the entire forest cover and biodiversity due to anthropogenic and environmental changes. The present study area 33% of the area is under forest cover with vastly diversified flora and fauna, which are affected and destroyed due to changing climate, natural calamities, and human interventions.In this situation, the study of Forest Cover Change and Vulnerability Analysis (FCVA) in Kallar watershed; part of Nilgiri biosphere reserve is unavoidable. Geospatial technologies along with Multi-Criteria Evaluation (MCE) based forest vulnerability analysis were adopted in this study. To assess the vulnerability, three major factors were considered viz., accessibility (road proximity, distance from settlement, slope, and elevation), demographic (population density), and forest cover types. The factors weights and ranks have been assigned through pair-wise comparison method; fuzzy membership function has been applied to assign subfactors weights. The vulnerability map categorizes the forest into four vulnerable zones viz., critical, highly vulnerable, moderately vulnerable, and least vulnerable zones. The resultant map is important in forest conservation by the forest department as highly vulnerable areas, which can be put into high consideration; at the same time, involving the people's participation is to engage in the sustainable forest management process.

Keywords: *Biodiversity, Environmental change, Vulnerability, Geospatial technology*

Introduction

Forest is a large area dominated by trees, and there are hundreds of more precise definitions of forest are used throughout the world; incorporating factors such as tree density, tree height, land use, legal standing and ecological function. Forests are the dominant terrestrial ecosystem of Earth and are distributed across the globe (Pan, Yude et.al 2013). Forests and woodlands are significant land cover covering nearly 40% of the total earth's surface and are the most biologically diverse ecosystems in the world; this is according to WRI, IUCN, and UNEP, 1992. India is one of the ten most forest-rich countries of the world along with the Russian Federation, Brazil, Canada, United States of America, China, the Democratic Republic of the Congo, Australia, Indonesia and Sudan.Together, India and these countries account for 67 percent of total forest area of the world (FAO, 2010).

Forest resources are very vital in sustaining the livelihoods of millions of people. These roles range from maintaining the ecological balance, providing fuel wood, habitat to important wildlife, soil and water conservation and purification of air. However, continued access to forest resources is increasingly getting challenged through deforestation and/or forest degradation (Michael and Janet, 2003). For several centuries the world's forests have been under strain due to escalating human population (UNEP, 2001). These activities have resulted in theloss of biodiversity, degradation of water catchments and increase in greenhouse gases which have far reaching effects. This has been blamed on poor monitoring and rule enforcement embedded in the institutions of management (Ayhan et al., 2004).

Deforestation and Forest Degradation

Deforestation is theconversion of any forest to other uses e.g. croplands, pastures, or urban land. It refers to reduction in productivity and/or diversity of a forest due to unsustainable harvesting (removals exceeding replacements, changes in species composition), fire (except for fire-dependent forest systems), pests, diseases, removal of nutrients and pollution/climate change (changes in productivity, total organic matter, and forest composition) (TERI, 1998).In many countries, deforestation, both naturally occurring and human-induced, is an ongoing issue. Deforestation causes extinction, changes to climatic conditions, desertification, and displacement of populations as observed by current conditions and in the past through the fossil record (Sahney et al., 2010). Between 2000 and 2012, 2.3 million square kilometres (890,000 square miles) of forests around the world were cut down. High rates of deforestation have been recorded in developing countries through the conversion of forest and woodlands into mainly farmlands (Michael and Janet, 2003). Forest cover, changes as a result of forest deforestation and degradation caused by different drivers acting at different levels of operation. These includes natural or/and anthropogenic factors acting at different times scales (FAO, 2001).

Deforestation has largely occurred in the tropics throughout the history. Around 3000 B.C, nearly 80% of India was forested (Warner F., 1982 and Khushoo, 1986).Subsequent invasions changed theentire landscape. The first era in deforestation was shortly after absorption into British Empire.The 1894 British Forest Policy accorded priority to commercial exploitation, state custodianship, and permanent cultivation.Second major deforestation was in the 1940s with demands of World War II and transition to independence for India in 1947(Tucker, R. P. 1988).

Vulnerability to forest degradation/deforestation

In this study, vulnerable area means anarea that is susceptible to change from forest to another land use type as a consequence of human activities. In reality, forest resources are degraded not only by human activities but also by other factors, such as repeated natural fire, pest infestation, diseases, natural disasters and war. Human activities are considered principally because of diverse sources of illegal activities, such as illegal logging, fuel wood, non-timber forest products (NTFPs) collection and hunting, which are recently the main factors that probably cause forest degradation in developing countries.Basically, three principal elements are considered in the analysis of the susceptibility of forests to degradation. These are: i) socio-economic factors, ii) the forest resources themselves, which are subject to be degradation, and iii) accessibility to the forest resource, which is understood as how easy the local people can enter the forest and related to the natural factors, such as slope, elevation, and distance from the river. Factors that constrain access to forests include distance from the road and distance form forest guard-station (Sheila A.W., et.al 2013).

The Nilgiri Biosphere Reserve

The Nilgiris (meaning the Blue Mountains) is an ancient land mass thrust upwards at the junction of the two major mountain ranges near the southern end of Indiasome 70 million years ago. The Nilgiris is an elevated physiographic zone - a massif. The Nilgiri massif is cloaked on its sides by very steeper slopes, surmounted by the hilly plateau of grassland, woodland, and savanna (Venugopal, 2004).Although it is a relatively small region, the Nilgiri Massif shows a remarkable variability in landforms, soils, flora, fauna, micro-climates, primates and human settlement patterns.

There are as many as ten different vegetation types in the Nilgiris, which are classified into the following four major zones (William Nobel, 1968). ***Dry Deciduous Forests*** of the hills occur below 1100 m and serve as sanctuaries for the extraordinarily rich wildlife. The Mudumalai wildlife sanctuary, one of the oldest in the country, is spread over a 1000 m high plateau. ***Moist Evergreen Forests*** occur up to 1800 m. They are now mostly lost to large-scale plantations of coffee and tea. ***Montane Zone Forests*** form a cool (average temperature: 10 - 15degree centigrade) dark temperate zone spreading out among the numerous clusters of native habitations. These forests, called the “Sholas” locally, occur between 1800 - 2000 m.

“Few districts in the world approximate the ideal natural laboratory for behavioral scientists more closely than does this one”, says a leading Nilgirilogist (Hockings, 1989).The Nilgiri Mountains of south India is considered unique by anthropologists, geologists, climatologists, botanists, as well as tourists. It has remained a subject of constant study and research over the last two centuries. The man-nature balance had continued undisturbed in the Nilgiris for thousands of years until the early 19^{th} century, when it became a British colony attracting, in due course, various developmental activities. Subsequently, the Nilgiris and its popular hill stations emerged as favorite places for the British population in India, for rest and recuperation, game and for raising commercial plantations. In the process, the traditional indigenous crops were replaced by ‘English’ vegetables and the natural forests, which gave way to commercial plantations of coffee, tea and other exotic species of trees. After Independence in 1947, the government of India accelerated the developmental process on the same lines as during the colonial period leading to a rapid growth of urbanisation and commercial plantations (Venugopal, 2004).

It leads to loss of biodiversity,the unrestrained spread of monoculture (tea, coffee, eucalyptus etc.) destroyed priceless tropical rain forests, montane forests, and grasslands which have evolved over millions of years. The Central Soil and Water Conservation Training and Research Institute (CSWCRTI) situated in the Nilgiris explain: “Biodiversity and degradation are related because of the differential abilities of species in utilizing site resources and developing afull cover for protection of land and water. The variety of species acts as an agent of soil conservation through proper cover development (ecosystem preservation). Increasing human interference has been instrumental in reducing biodiversity in the Nilgiris leading to the disappearance of thenatural ecosystem.” Increasing pressure on land for agriculture and monoculture plantations displaced an alarmingly high proportion of natural forests and grasslands leading to an extensive loss of biodiversity and turning the Nilgiris into a biodiversity ‘hotspot’, as identified by World Wildlife Fund, India (1995).

Especially Kallar watershed has been situated in part of Nilgiribio-reserve, which is highly affected by frequent landslides, forest fire and drought due to climate change. In this case, thepresent paper aim’s to identify the forest cover changes and vulnerability in Kallar watershed. Following objectives are used to achieve the goal. To identify the forest cover changes, to analyses the vulnerability zones through multi-criteria and geospatial approach, to suggest the conservation measures.

Study Area

The study area is located between 11˚17′0″ N to 11˚31′0″ N latitudes and 76˚ 39′ 0″ E to 77˚ 8′ 45″ E longitudes with an area of about 1,283 sq.km. Covering three districts, namely, The

Nilgiris, Coimbatore, and Erode. It altogether covers 7 taluks such as Coonoor, Kothagiri, Udhagamandalam, Mettupalayam, Coimbatore north, Annur, and Sathyamangalam with 79 Revenue villages, (Figure 1a). The maximum and minimum elevation of the study area ranges from 177m to 2,615m above MSL, (Figure 1b). About 50% of areas are mountains, covered with diverse plant communities that form various types of forest and hill farming like Tea, coffee, vegetables, and orchards. The climate of this area is temperate and salubrious for more than half of the year. The average day temperature of the subwatershed fluctuates between 20°C and 30°C. The average rainfall is about more than 1,400 mm. The maximum rainfall is during the month of October and November. The winter is relatively cool. The Kallar streams flow from Southwest to Northeast and it connects the Bhavani River at Mettupalayam, which finally empties into Bhavanisagar Dam which lies in the northeastern part of the watershed. Bhavanisagar Dam primarily serves as a source of irrigation and hydroelectric power generation. The area covered by clay soil, loamy soil and rock outcrop on steep to narrow sloping grounds. Geologically, the area is made up of granite and fissile hornblende-biotite gneiss. Geomorphologically, the watershed is characterized by structural hills, denudational hills, narrow gorges, and intermountain valleys.

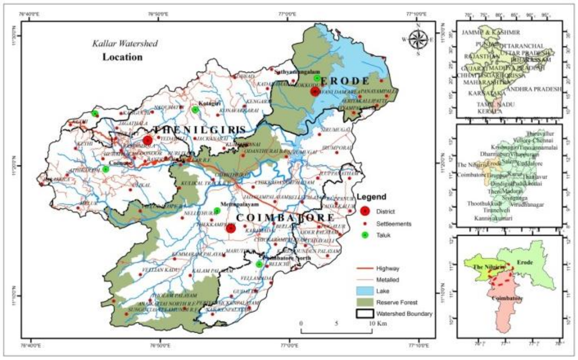

Figure 1. Study Area.

Forest Types and Physiognomy

Kallar watershed occupies avariety of forest types and physiognomy. The main forest types are Wet evergreen and semi-evergreen climax forests and secondary or degradation stages, Dry evergreen or semi-evergreen climax forests and degraded formations, Moist and dry deciduous climax forests and degraded stages, Plantations, and Montana formations;the subforestcategories, and its aerial extent have been given in table 1 and fig 2a. Physiognomy is a combination of the external appearance of vegetation, its vertical structure, and the growth forms of the dominant taxa. Physiognomy is an emergent trait of the community - Desert, Deciduous forest, and tundra, etc. (table 2 and fig 2b).

Table 1. Sub Forest Type in Kallar watershed

Sub-Forest Types	Area in km^2	Area in %
High elevation wet evergreen climax and potentially related forests	6.49	1.58
Degraded or natural Savanna formations in potential area or wet evergreen forests	1.59	0.39
Dry evergreen or semi- evergreen climax forests and potentially related formations	22.87	5.58
Dry deciduous climax forests and potentially related formations	366.26	89.29
Montane forest	5.62	1.37
Montane grassland	3.91	0.95
Montane mosaics of savanna, thickets, plantation and orchards	3.46	0.84
	410.20	**100.00**

Table 2. Forest Physiognomy Type in Kallar watershed

Forest Physiognomy Types	Area in km^2	Area in %
Dense to moderately disturbed wet evergreen forests	12.11	2.95
Dense to moderately disturbed dry evergreen forests	22.87	5.58
Dense deciduous forests	5.20	1.27
Woodland to Savanna woodland	78.77	19.20
Tree savanna to grass savanna	19.27	4.70
Scrub-woodland to thicket	192.62	46.96
Discontinuous thicket to scattered shrubs	75.90	18.50
	410.20	**100.00**

Source: Indian Biodiversity Portal

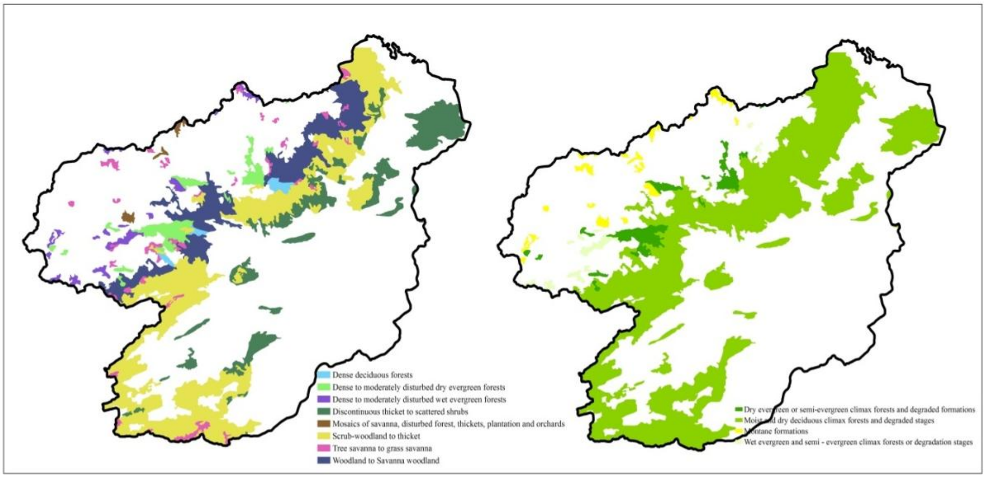

Figure 2. a) Forest Physiognomy **b)** Major Forest Type

Data and Methodology

In this paper, the following data and methodology has been applied to analysis the forest cover change and vulnerability. The suitable criteria's are accessibility (road proximity, distance from settlement, slope, and elevation), demographic (population density), and forest cover types. This study has used Survey of India (SOI) toposheets 58 A/11, 15, 16, and 58E/3, 4,US Defense toposheet (1950) LISS IV imagery (2015), census (2011)to create aforesaid thematic layers with the scale of 1:50,000. This study used an Analytical Hierarchy Process (AHP) and fuzzy membership based weighted overlay methodological approach to integrate all thematic layers for achieving the designed objectives.

An AHP hierarchy is a structured means of modeling the decision at hand. It consists of an overall goal, a group of options or alternatives for reaching the goal, and a group of factors or criteria that relate the alternatives to the goal. The criteria can be further broken down into sub criteria, sub-subcriteria, and so on, as many levels as the problem requires. In this study, the Analytic Hierarchy Process (AHP) developed by Saaty (1980) was used as a decision-aiding method to finalize the weights assigned to different themes. The weights of the different themes were assigned on a scale of 1 to 9 based on their influence on the vulnerability. The fuzzy liner membership method has been applied to assign the sub-criterion weight. The Fuzzy Linear transformation function applies a linear function between the user-specified minimum and maximum values. Anything below the minimum will be assigned 0 (definitely not a member) and anything above the maximum 1 (definitely a member).

To demarcate forest vulnerability, after assigning weights, all the thematic layers were integrated (overlaid) step by step using ArcMap software. The integrated layers were derived from the following equation to calculate the Forest Vulnerability Index (FVI):

FVI = *(RDi*RDj +SDi*SDj + Ei*Ej + PDi*PDj + FCi*FCj)*

Where RD = distance from road, SD = distance from settlement, E = elevation, PD = population density, and FC =forest cover. i' = normalized weight of a theme, 'j' = normalized weight of the individual features of a theme. The total ranges of FVI values were divided into five equal classes to demarcate the forest vulnerability zone.

Result and Discussion

Forest Cover Change

In this study,forest cover changes were analysedfor the year 1950 and 2015. In 1950, the forest cover occupies 801.73 km^2 (62.48 %) which includes tea plantation and 662 km^2 (51.9%) in the year 2015. The non-forest area is 481.43 km^2 (37.52%) which include agriculture, settlement and wasteland in 1950,and 621.15km^2 (48.40%) in the year 2015 (fig 3a & b). After independence there are several developmental activates, that were made in this region,such as dam constructions, new settlements, tea plantation (commercial) and tourism which leads to the decrease in forest cover;on the other hand, these activities and management plans are inevitable.

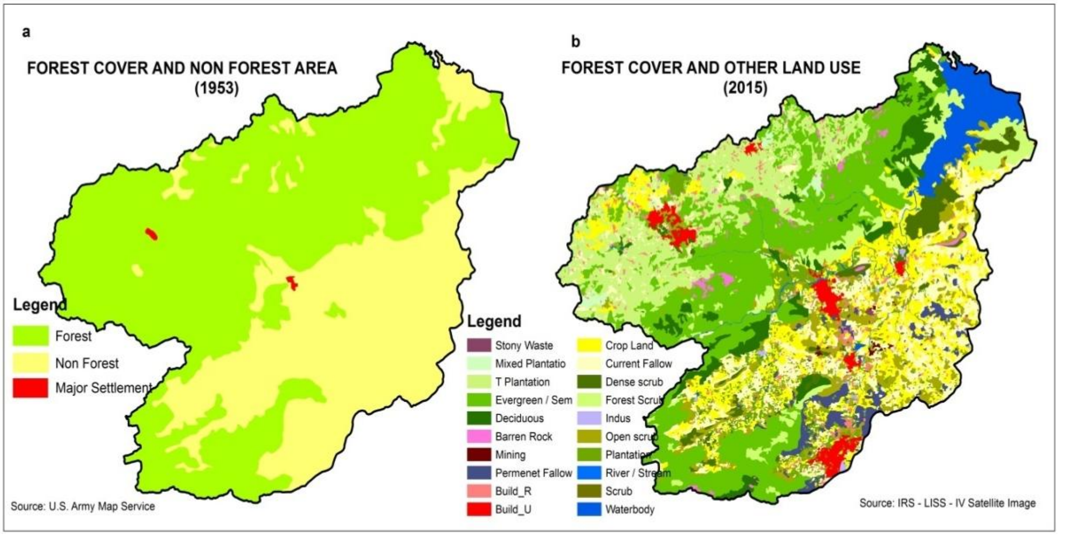

Figure 3. a) Forest Cover and Non Forest **b)** Forest Cover and Landuse

Rate of natural forest cover change

Mean annual rates of forest cover change (MARFCC) between different image dates were computed based on the time series classified images using the equation as follows:

$$\text{MARFCC (\%)} = \frac{\text{Forest Area } t_2 - \text{ Forest Area } t_1}{\text{Forest Area } t_1 * (t_2 - t_1)}$$

Where: t1 = the year in which the older image was captured; t2 = the year in which the recent image was captured [(-139.72 / -112017.73)*100 = 0.124]. It, therefore, follows that natural forest will be lost at a mean rate of 0.124%.

Forest Vulnerability Modeling

The following criterionsconsidered for forest vulnerabilitysuch as, accessibility (road proximity, distance from settlement, slope, and elevation), demographic (population density), and forest cover types. The criterion weights were given on the basis of importance to vulnerability based on pair-wise comparison viz.,distance from road (0.25), distancefrom settlement (0.21), slope (0.17) elevation (0.12), forest cover (0.08) and population density (0.14). The criterions weight and spatial distribution of individual features were given in table 3, and fig.4.

Table 3. Criterion weights for forest vulnerability

	Elevation	Slope	Distance from Road	Distance from Settlement	Forest Type	Population Density	Normalized weight
Elevation	4.5/4.5	4.5/6	4.5/9	4.5/7.5	4.5/3	4.5/5	0.12
Slope	6/4.5	6/6	6/9	6/7.5	6/3	6/5	0.17
Distance from Road	9/4.5	9/6	9/9	9/7.5	9/3	9/5	0.25
Distance from Settlement	7.5/4.5	7.5/6	7.5/9	7.5/7.5	7.5/3	7.5/5	0.21
Forest Type	3/4.5	3/6	3/9	3/7.5	3/3	3/5	0.08
Population Density	5/4.5	5/6	5/9	5/7.5	5/3	5/5	0.14

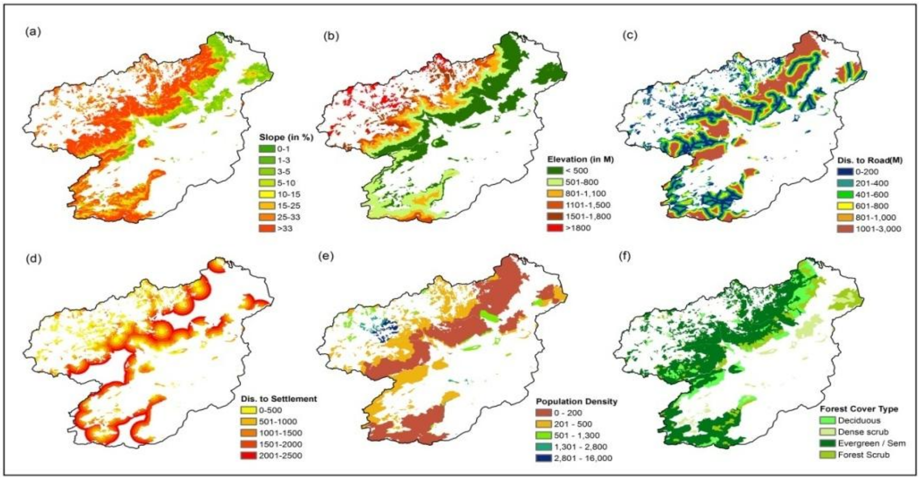

Figure 4 a) Slope **b)** Elevation **c)** Distance to Road **d)** Distance to Settlement **e)** Population Density **f)** Forest Type

Accessibility Factor

Accessibility to the forest resources which is one of the factors related to theforest-people relationship is understood as how easily local people can go to the forest. The ease of access to the forest resource (that is forest area near to the road, settlement, river, low and less steep slope area), to widely dispersed local market enables large number of people to generate income from forest products (Dien, 2004).

Elevation: The role of elevation in constraining accessibility tothe forest was analysed. In this study area the minimum and maximum elevation range from < 500 to > 2600, which are classified into five classes <500, followed by 500-800, 800-1100, 1100-1500, 1500-1800, and 1800-2500.And their weights were assigned through fuzzy linear membership, the maximum weight was assigned to least elevation (<500) and the minimumweight was given to highest elevation (1800-2500), the spatial distribution of elevation map, shown in fig.5a.

Slope: **I**t'san important physical parameter to assess the vulnerability, the gentle slope is highly vulnerable than steep slope areas, the slope class range from 0 - >33 viz., 0-1, 1-3, 3-5, 5-10, 10-15, 15-25, 25-33 and > 33. The maximum weight for gentle to moderate slope (0-15%) and minimum weight was assigned to moderate to steep slope (15 - >33), the spatial distributions and its weighted map is shown in fig.5 b.

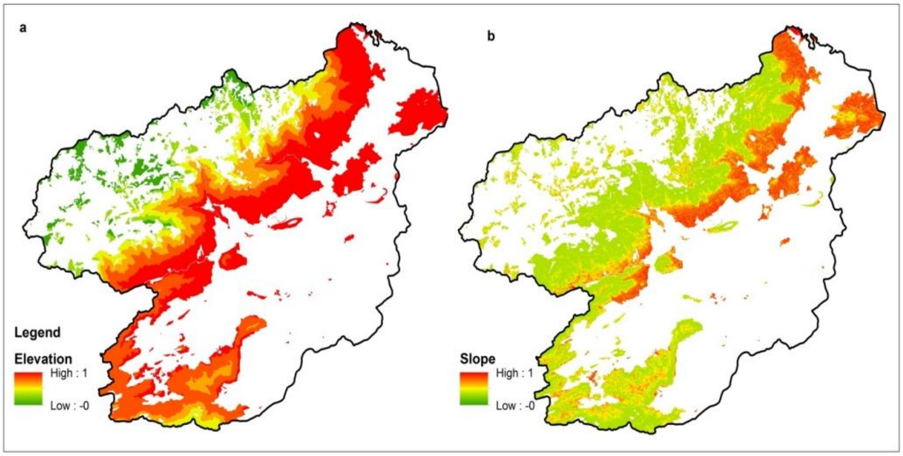

Figure 5 a) Elevation **b)** Slope

Distance from Roads:plays an important role in the forest vulnerability. National Highway 67 (Coonoor to Mettupalayam - 40 km) and State Highway 15 (Kothagirito Mettupalayam- 33 km)network's across the forest cover in Kallar watershed.The closer the forest is to the road the most vulnerable it is to vulnerability, thus distance from roads to theforest was classified into five classes viz., 0 to 200m followed by 201 to 400m, 401 to 600m, 601to 800m, 801 to 1000m and > 1000m. For assign, the weight the maximum has been given to closer to the forest (0-200m) while minimum weight was assigned to far away from the forest (>1000 m), fig.6a.

Distance from Settlement: this is also one of the cultural factorfor forest vulnerability.Settlements are growing rapidly, especially three important settlements (town) namely Coonoor, Kothagiri, and Mettupalayam were located adjacent to both sides of the forest cover of Kallar watershed. The settlements were closer to the forest is most vulnerable. The distance from settlements was classified into five classes viz., 0 to 500m, 501 to 1000m, 1001 to 1500m 1501 to 2000m and > 2000m. The settlement distance closer to theforest (0-500m) was given maximum weight and theminimum has been assigned to away from the forest (>2000m), fig.6b.

Demographic Factor

The population is yet another major factor for forest vulnerability; present study area has beenfacing over-population, migration of people (for Tea plantation), and tourist in several years.Due to increasing population, the settlement areas were also growing gradually. The census 2011 data has been used to calculate the population in Kallar watershed.

Population Density: the calculated population statistic was later divided by the locational area in order to compute population density per location, which was then reclassified into five classes viz., very low, low, moderate, high and very high. Coonoor, Kothagiri, Mettupalayam, and Periyanayakanpalayam are the areas with high populationdensity (>2000), whichare located near to the forest cover areas.The minimum weight was assigned to lowest density (<200) while maximum weight was given to high density (>2000). The spatial distribution map is shown in fig.7a.

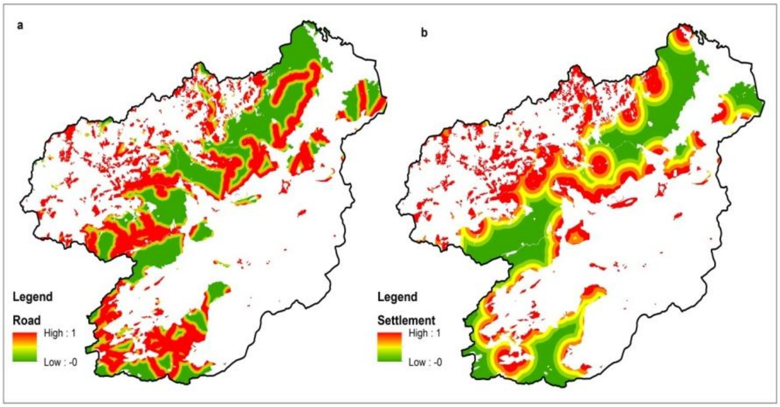

Figure 6 a) Distance to Road **b)** Distance to Settlement

Forest cover: its shows the current status of the forest and which type of forest cover will be highly affected by thevulnerability. The forest classes were prepared from LISS IV data by using thehybrid method; the classes are evergreen/semi-evergreen, deciduous, forest scrub, and dense scrub.Except, evergreen forest, all other types were severely affected.The maximum weight was given to forest scrub while minimum weight has assigned to evergreen forest as shown in fig.7b.

Forest Vulnerability

The generated thematic layers were overlaid and prepared forest cover vulnerability map. In this, distance from theroad, settlement, and the slope factor were played amajor role in vulnerability analysis. The results from the vulnerable map (fig.8) indicate that risk degree varies from the boundary towards the inner side of the forest. This result shows that forests closer to settlements have ahigher probability of being harvested. Accessibility was given more weights and thus contributes heavily on the final vulnerability map. Accessibility included factors like road network, slope, and elevation thataffect accessibility greatly. The vulnerability map has been classified the area into four vulnerability classes viz., highly vulnerablezone with 98.0 km^2 (19.7%), followed by moderately vulnerable zone with210.8 km^2 (42.4%), marginally vulnerable zone with 107 km^2 (21.5%), and low vulnerablezone with 81 km^2 (16.3%). The combination of slope and elevation contributes greatly to extend of exploitation; elevation and distance to a road network contribute a lot to deforestation. The result clearly shows that closer the settlement, road, gentle slope and low elevation, the higher the probability to be deforested, than those on steep slopes, far from the settlement and on high elevation.

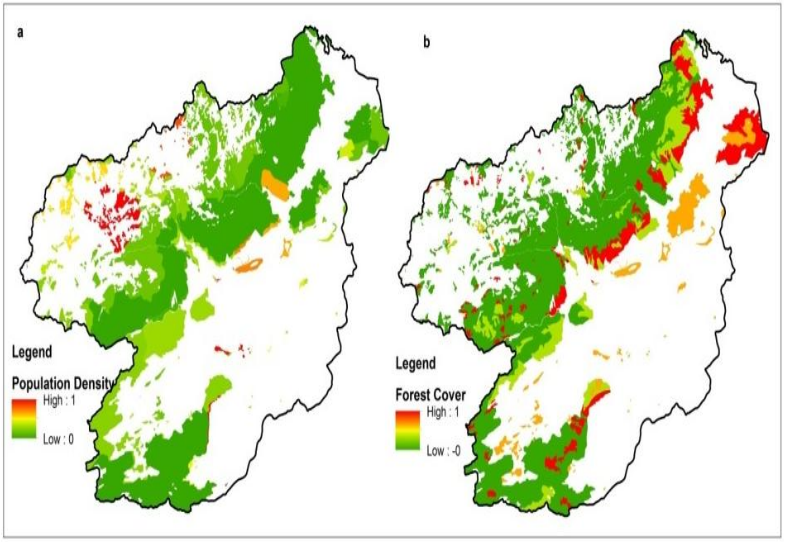

Figure 7 a) Population Density **b)** Forest Cover Type

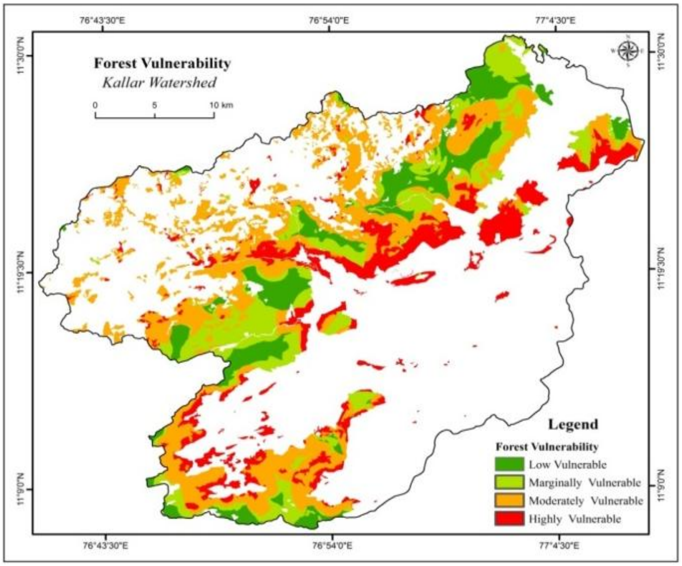

Figure 8 Forest Vulnerability

Conclusion

The present study attempted to analyse the forest cover changes for several decades and identified the areas having possibilities to be vulnerable. The geospatial techniques combined with multi-criteria approach were adopted. Most of the forest cover has been converted into tea plantation in the hilly areas, agriculture and other plantation inthe foothill areas; apart from that, those vulnerable areas are also affected by soil erosion and landslides, which in turn leads to the deforestation. The rate of forest cover changes is 0.124% in 1953 and 2015. The resultant map is important for forest conservation to the forest department as highly vulnerable areas, which can be put into high consideration; at the same time, involving the people's participation to engage in the sustainable forest management process.

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