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Spatio-temporal Dynamic Alteration of Forest Canopy Density based on Site Associated Factor: View from Tropical Forest of Nepal

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Abstract : Forest Canopy Density is a dynamic process mediated by various natural and anthropogenic factors. It can be changed over time and locations in the same forest type and landscape. However, human dimensions are considered as the primary force of landscape change and subsequent forest canopy loss in tropical regions of the world. Many studies have been indicated that roads have a far greater impact on forests than simply allowing access for human use. Similarly, rivers have been used as means of transportation, hence illegal logging and felling further deplete forest canopy density. The main objective of this study was to investigate the spatio-temporal dynamic alterations of Forest Canopy Density (FCD) across with site associated factors such as biophysical, physical and human interferences in tropical region of Nepal from 1988 to 2001. Landsat TM and ETM+ of 1988 and 2001 were used to assess the spatial and temporal dynamic alterations of FCD. This analysis revealed that distance to human settlements at P=<0.01, rivers, human interferences (path and fire) and species composition had a statistically significance at P=<0.05 level. However, other factors did not show any significant relation. So, we concluded that understanding of dynamic alterations of FCD with respect to factors was quite complex phenomena. Other surrounding environment could also play a significant role. A comprehensive analysis could be required to understand such complexities. Therefore, additional factors such as climatic, biophysical, social, and institutional with respect to spatio-temporal variability should be considered for the better understanding of canopy dynamic.

Key Words : Forest canopy density, Dynamic alteration, Spatio-temporal, Site associated factors.

1. Introduction

The importance of forest is well understood by economic & ecological aspects (Franklin & Woodcock, 1997; Franklin, Woodcock & Warbington, 2000; Skole & Tucker, 1993). Forest canopy is essential to improve environmental and economic health regarding with various aspect of human life (Morrow *et al.*, 2001). Forest area and its changes are an important and supposedly easily

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measurable indicators for sustainable resources management in larger areas (Kleinn, 2001). Importantly Forest Canopy Density (FCD) can be used to understand and measure the forest condition efficiently from satellite images (Urquizo *et al.*, 1998 in Panta, 2003). Human influences to transform forested lands are one of the great forces in global environmental change and loss of biodiversity. Thirteen and half million hectares of tropical forest is cleared annually for agriculture, pasture, timber products and infrastructure development (FAO, 2001; Geist & Lambin, 2002).

FCD is a dynamic process and continually changing in response to natural and anthropogenic disturbances (Panta, 2003; IDAHO, 2005). The humid tropical forest becomes more vulnerable due to human population, and economic and social development. (Achard *et al.*, 2002). Population pressure, political instability, economic development activities are the major factors contributing to deforestation and forest degradation (Hussin & Sha, 1996). Forest canopy of tropical influence by many human interference such as railways, roads, electricity power line, channels, quarrying and mining (Longman & Jenik, 1974). However, the frequency of disturbances in a forest varies among localities (Bianchini *et al.*, 2001). Similarly, Nepal's forest are being depleted. It was 6.4 million hectares in 1964, but reduced to 3.9 million hectares in 2000 (ADB, 2004). Further, Terai plains of Nepal to follow the human dimensions of forest change (Nagendra *et al.*, 2005). The impact of humans on the natural environment has increased dramatically over the last quarter of a century (Schweik *et al.*, 2003). After malarial eradication in the 1960s, there has been far greater recent deforestation in the Terai (Schweik *et al.*, 1997; Mathews *et al.*, 2000 in Nagendra, 2002).

Remote sensing is a potentially useful tool for providing a spatial synoptic view of changes in forest condition and cover over time (Millette *et al.*, 1995; Nagendra & Gadgil, 1999; Schweik & Green, 1999; Nagendra, 2001 in Nagendra, 2002). Moreover, Carmon *et al.* (2002) has done vegetation classification & canopy change analysis using ancillary & field data. Huang *et al.* (2001) estimated FCD by developing empirical relationship with Landsat data. Andersen (1998) also reviewed methodologies to estimate the vegetation and forest variables combined with field inventory and high resolution satellite data. King (2002) developed methods for assessment of characterizing forest structure and regeneration condition with respect to natural and anthropogenic factors. Ruchaemi (2001) studied about the impact of forest fire in forest dynamic. Schweik *et al.* (2003) has analyzed multi date Landsat TM linking with GIS database on roads and topography to identify the rapid change in forest area in Chitwan, tropical of Nepal. Mahato (2001) has also analyzed the Landsat TM data in the same region to classify the different forest types based on density classes. However, the analyses regarding dynamic alterations of FCD integration with multiple factors is still far from many researcher's eye. Most of the researches have concentrated with single or few variables. Therefore, in this study, we intended to integrate the various site associated factors that could have possibly influence on dynamic alterations of FCD in Chitwan tropical forest of Nepal. The main objective of this study was to detect the spatial and temporal dynamics of FCD over the years 1988-2001 with respect to possible site associated factors such as settlements, roads, rivers, human interferences, and species composition on the local level using GIS and RS techniques.

2. Materials and Methods

1) Study area

Terai tropical forest of Chitwan district of central development region in Nepal (83°54' 45'' and 84° 48' 15'' E and 27°21' 45''and 27°52' 30''N) has been selected for the study (Fig. 1). This study area is Shorea robusta forest corridor connecting between the middle mountain range in the North and the Royal Chitwan National Park in the South. This forest is dominated by pure stands of Shorea robusta and the richest with diversify flora and fauna. The coverage of forest resources are consisted by mixed hardwood and reverain forest combined by *Accacia catechu, Dalbergia sissoo, Terminalia tomentosa* and *Adina cardifolia* with mixed forest and grassland. This area is comparatively suitable for this study because of highly populated forest bounded and interspersed with various physical, biophysical, and human settlements factors. Hence, we hypothesized that the interaction of all these factors could have strong correlation with spatio-temporal dynamic alterations of FCD.

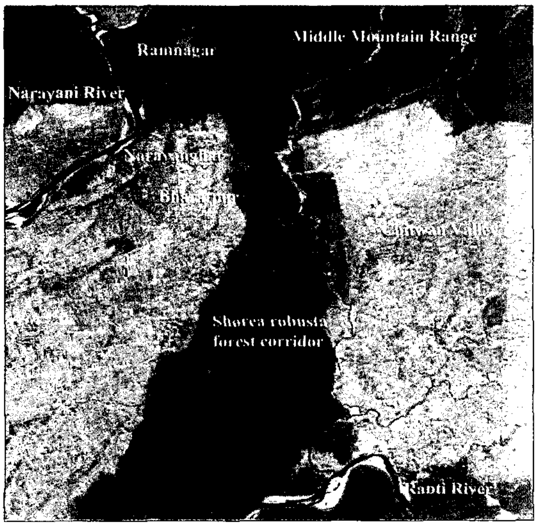

Fig. 1. ASTER Image FCC (231) of 2005 Showing tropical forest of chitwan, Nepal.

2) Data use

Landsat TM of Oct. 12th, 1988 and ETM+ of Oct. 24th, 2001 with same seasonality of seven bands covering the whole area of Chitwan valley were used for this study. Also, topographic map of 1994 with scale of 1:25,000 of Chitwan district published by Survey Department of HMG of Nepal were used for georeferencing satellite imagery and to derive the vector layer of settlements, roads, and rivers of the study area. Site associated factors of species composition and human interferences such as logging, felling, lopping, debarking, girdling, coppicing, fire and path recorded from 69 plots (35 from site1 and 34 from site2) were also used in this analysis. FCD Mapper was used for processing of remotely sensed data and ILWIS for performing GIS operations to analyze the factors. Correlation coefficients and some statistics were also used for data analysis.

3) Data processing

Landsat TM of 1988 was geo-referenced using 1:25,000 topographic map of 1994. Eight points were identified and matched with points on the topo-sheet to correctly georeference. Similarly, Landsat ETM+ of 2001 was geo-referenced using image-to-image registration method where 1988 image was taken as a master while 2001 as a slave. At the same time, using the nearest neighborhood method for geo-coding of the images has been performed. Similarly, human settlements, roads, and rivers maps were digitized from a topographic map. Then digitized maps were converted in the rasterized form using ILWIS. GIS operation including distance calculation function was performed to produce distance maps of human settlements, roads, and rivers. These maps were used for further analysis of dynamic alteration of FCD. Human interferences and species composition recorded from the sample plots were also analyzed using MS Excel spread sheet to establish the relationship between variables.

4) Alteration of FCD with reference to temporal factor

To examine the dynamic alteration of FCD in the tropical region of Chitwan Nepal from 1988 to 2001, we selected FCD Mapper introduced by Rikumaru (1996) to analyze the dynamic alteration of FCD in large area. It has already tested in some South East Asian countries and produced average accuracy of 92% (Rikimaru, 1996). FCD model based FCD Mapper can stratify the forest into 11 density classes ranging from 0% to 100%. The model comprises of bio-physical phenomenon modeling and analyzes data derived from four indices namely: Advanced Vegetation Index (AVI), Bare Soil (BI), Shadow Index (SI) and Thermal Index (TI) using Landsat TM imagery. FCD Mapper calculates canopy density in percentage of each pixel using the four indices. Hectare was used as the unit of area in grid system. The information is rather confusing because very few pixels represent some of the classes that may not be good enough for analysis. Therefore, to overcome this problem, extra steps were adopted for reclassification operation and finally six classes of FCD map was obtained from each year.

5) Alterations of FCD with reference to site associated factors

The main objective of this study was to investigate the spatio-temporal dynamic alterations of FCD with respect to possible site associated factors such as settlements, roads, rivers network, human interferences and forest composition. Among these, roads, rivers and settlements were analyzed by using map interpolation. Roads, rivers and settlements maps were digitized, rasterised, interpolated and a continuous distance map of each variable was generated. The FCD map of 1988 and 2001 were overlayed with individual maps such as roads, rivers, and settlements. Finally, relation was analyzed using map attributes and results were presented in the form of tables and graphs. Furthermore, statistical tests were performed between FCD recorded from ground truth data and thematic layers derived from topographic maps such as road, river and settlement.

3. Results

Mapping FCD based on biophysical approach is a simple and straightforward method. This method has been used by many researchers and has given different results. Most of the results from previous research have claimed high correlation between the reflectance and field measurement of FCD, if the field measurement has been taken at the same time with the satellite overpass. However, in this analysis, field measurements were collected at different time. This fact gave another challenge for this research: Can Landsat imagery reasonably contribute to FCD mapping over a relatively prolonged period with different seasonal data?

1) Alterations of FCD from 1988 to 2001

Forest canopy density slightly decreased in lower classes, however, steadily increased in other higher classes in 2001 compared with 1988 (Fig. 2 & 3). Our finding also agreed with other authors such as Nagendra (2002) who mentioned interviews with local users which indicated that the forest had been fairly well protected from mid-1995 onwards. However, area indicated by the red arrow showing the patch of national forest clear felled by government plan for resettlement (Fig. 2) hence the degraded canopy classes were the most dominant canopy cover. Moreover, canopy density has been

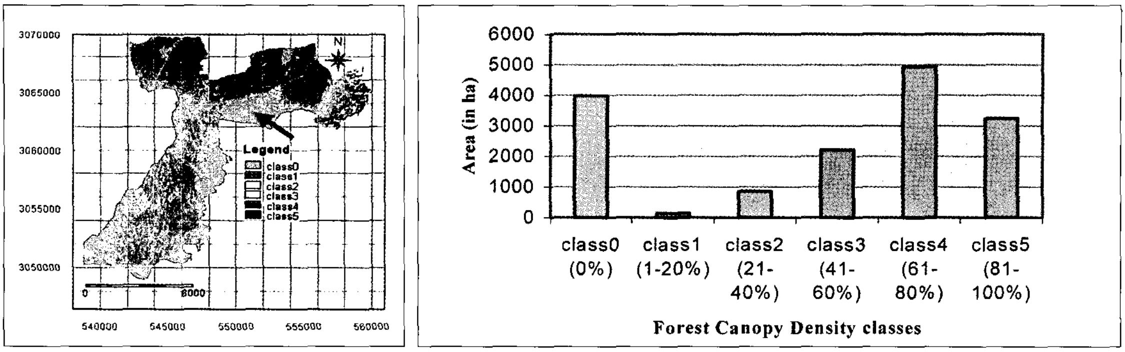

Fig. 2. FCD classes distribution in 2001 map & graph.

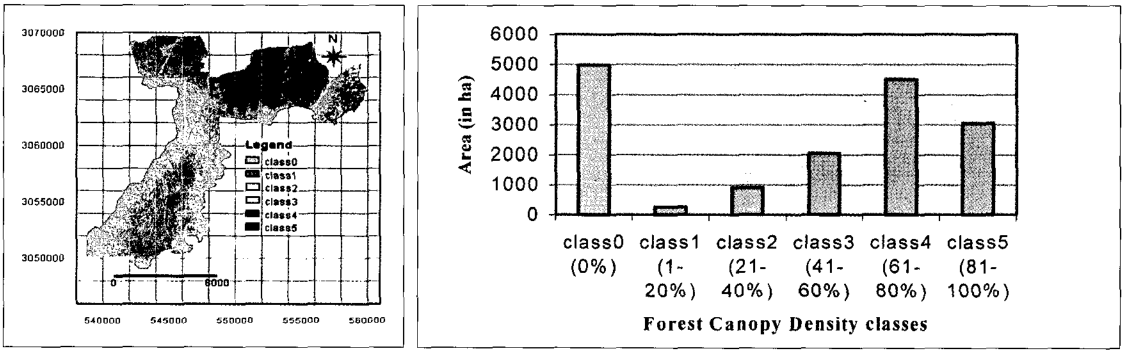

Fig. 3. FCD classes distribution in 1998 map & graph.

increased in higher classes unexpectedly and it was increased by 5.5% between 1988 to 2001.

2) FCD and site associated factors

(1) Influence of settlements, roads and rivers on FCD

Fig. 4 shows the dynamic alteration of each FCD class with respect to distance from human settlements, roads and rivers. Although the positive changes of FCD have observed in some density classes, the lower density classes within 2 km from the settlements, roads and rivers were remarkably affected and converted into the other class. It shows the FCD close to the settlements, roads or rivers was undoubtly vulnerable.

(2) Influence of species composition on FCD

A total of eight forest types were classified using available data. These were the association of *Albizzia-Myrsine, Albizzia-Trewia, Albizzia odoretissima, Dalbergia sissoo,* mixed broad leaved,

Myrsine capitellata, Trewia nudiflora and Shorea robusta. A wide variation in the canopy density of different canopy dominant species (Fig. 5) was found in the site1 whereas there was almost all same species in site2. So, site 2 data was not analyzed. The canopy density of *Dalbergia sissoo and Trewia nudiflora* was found to be the highest compared with other dominant species types followed by *Albizzia odoretissima, Albizzia-Myrsine* and mixed broad -leaved forest. While *Myrsine capitellata* dominated canopy areas have the least canopy density.

3) Influence of human interferences on FCD

Figs. 6 & 7 show the influence of human interferences on dynamic alterations of FCD and the graphs in the figs. show the mean forest canopy %

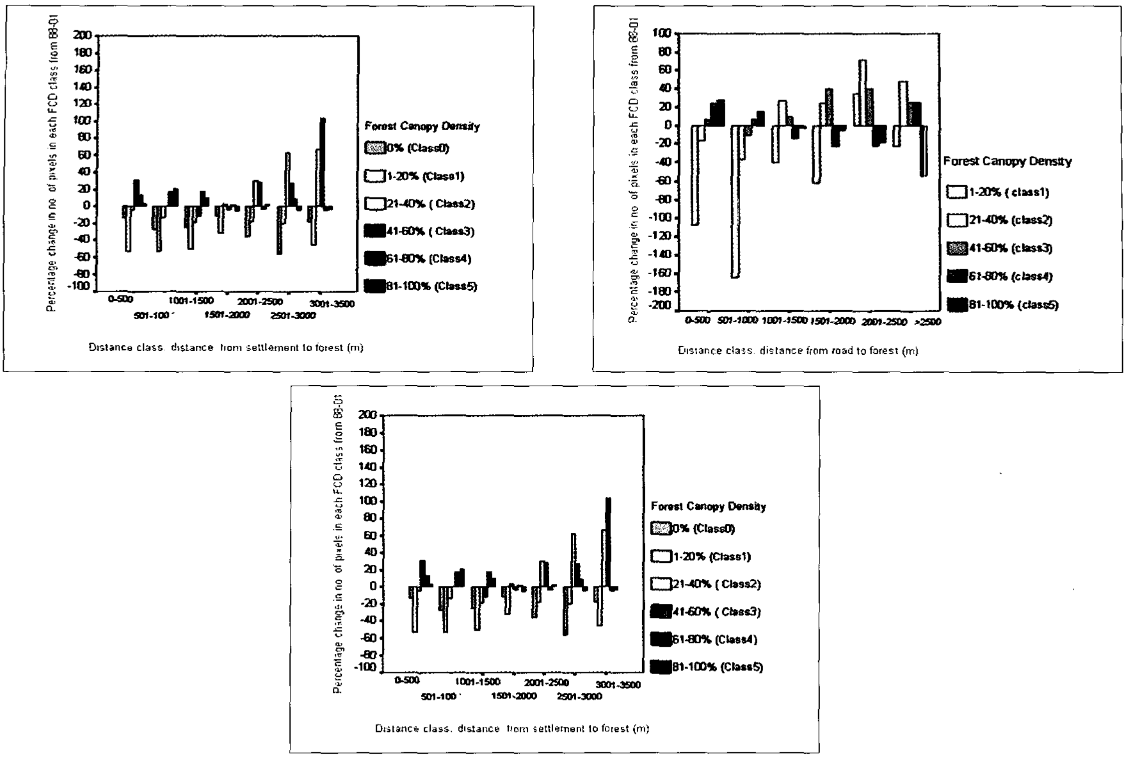

Fig. 4. Percent changes of FCD classes in relation to settlement, road and river.

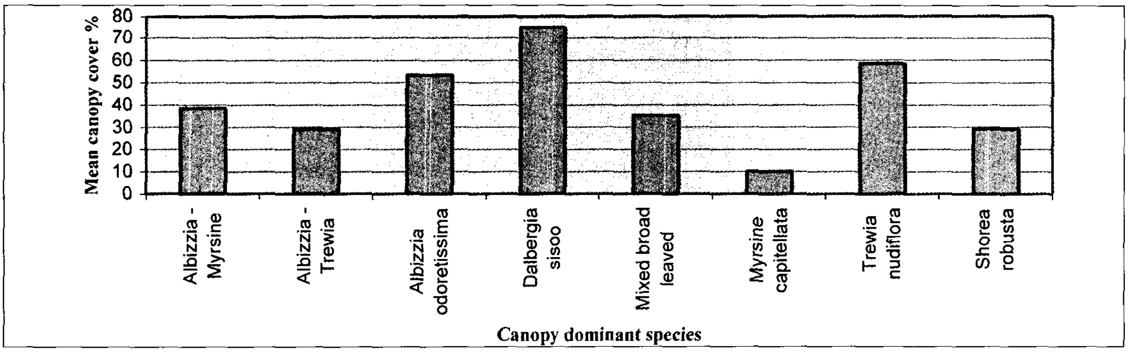

Fig. 5. Relationship between canopy dominant species and forest canopy density.

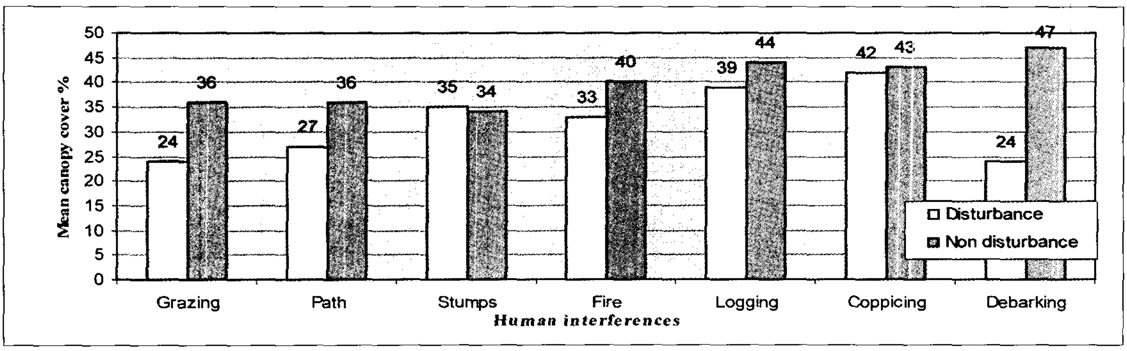

Fig. 6. Canopy cover % relation with disturbed and undisturbed area (site1).

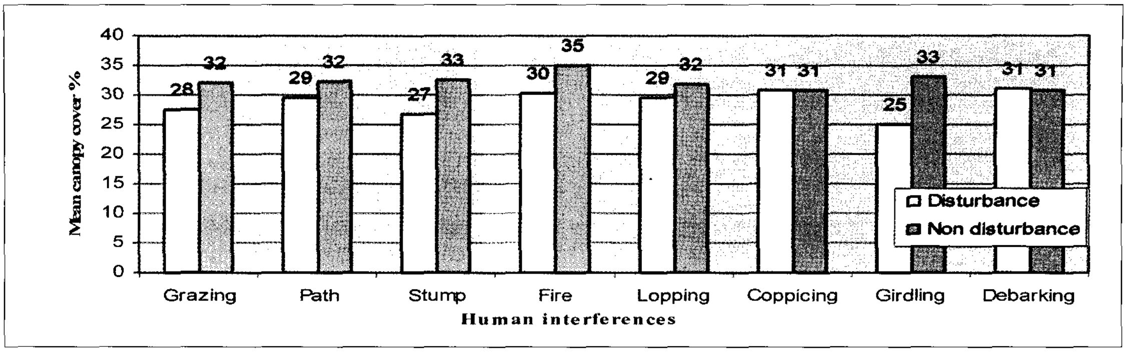

Fig. 7. Canopy cover % relation with disturbed and undisturbed area (site2).

relation with the area that disturbed and undisturbed from human interferences. Moreover, FCD is relatively low in the area where human interferences were existed. However, some human interference such as coppicing, stumps in site1 and coppicing, debarking in site2 did not show remarkable distinction between disturbed and undisturbed area. More interestingly, same factor such as debarking affected more on dynamic alteration of FCD in site1 but no any effect in site2.

4. Discussion

1) Alterations of FCD with respect to temporal factor

The image analysis showed the qualitative and quantitative improvement of the forest has observed in 2001 (Fig. 3). It showed that the forest condition in 2001 was comparatively much better than the condition in 1988. This result may be due to the method used because FCD was estimated by FCD model. However, FCD model used by many researchers has been conformed to reliable results in different parts of the world. Further, map accuracy has assessed with ground truth data of 2001 and produced 71% accuracy (Table 1).

2) Alterations of FCD with respect to site associated factors

The analyzed figures. revealed that FCD was clearly altered by the distance from the settled area, rivers and roads. Combination of these three variables can be used for the detection of dynamic alteration of FCD. In this study, it was observed that the dynamic alteration of forest canopy was clearly related to the extent of human dimension in which distance from the settled area was the most prominent factor (Fig.

Table 1. Confusion matrix for accuracy assessment

	No- forest	Open forest	Closed forest	Total	Error of Commission (%)	User Accuracy (%)
No-forest	6	9	1	16	64	36
Open forest	2	23	1	26	36	64
Closed forest	3	4	20	27	26	74
Total	11	36	22	69		
Error of Omission (%)	45	36	9			
Producer Accuracy (%)	55	64	91			71
The overall accuracy is 71%						

4). This finding also agreed with other authors such that forestlands closer to the roads and human settlements are easily accessible and less work time for the collection of forest products (Shrestha, 1999). Schweik *et al* (2003) also mentioned that cause of deforestation in Chitwan was mainly due to the expansion of agriculture and infrastructures since 1950s. Moreover, a huge amount of forestland between Himalayas and the Terai has been cleared to provide room for crops, livestock, and human settlement (ADB, 2004).

Therefore, those area closer to the roads and settled area are more vulnerable to the canopy loss. It can be seen that FCD remained almost constant for the area far from the settlements during 13 years while FCD decreased significantly and hardly increased for the area close to the settlements. In this analysis, distance from the roads to the forest is not statistically significant factor (Table 2), however close distance of roads to the forest is clearly vulnerable for dynamic alteration of canopy. Moreover, positive change in FCD with respect to human settlements and roads suggests that aforestation and conservation program seems to be successful within easily accessible range. Similarly, high FCD classes (untouched forest) could possibly be difficult to encroach in comparison with low FCD classes. It may be due to effective protection, under direct supervision of community members, terrain, slope, unfertile soil, and water scarcity.

Table 2. Pearson correlation test for settlements, roads & rivers in relation to FCD.

Pearson correlation test					
		Canopy Cover %	Dist _road	Dist _river	Dist _settle
Canopy Cover	Pearson correlation	1	-0.04	**.429***	**.449****
	Sig (2-tailed)	.	0.822	0.011	0.008
	N	34	34	34	34

Note: * = 0.05, ** = 0.01

Further, in the study area some of the rivers are seasonal and some are perennial. Those area which are isolated by a river, are rather far from forest guard's vigilance and not regularly inspected by them, hence illegal felling is relatively frequent and FCD is reducing with close distance from the river. Similarly, close to river mostly found *Khair-sissoo* forest and this forest types are sparsely distributed. So, it could be observed high canopy degradation due to sparse vegetation (Fig. 4). Moreover, these forest species are more intended to illegal cutting due to its commercial value hence canopy could be dramatically altered. In addition, these forest species have very small leaves showing lower FCD in the area. FCD could be highly affected by morphology of the leaves.

Similarly *Dalbergia sissoo, Trewia nudiflora, and Albizzia odoretissima* are the main canopy dominant species in the study area (Fig. 5). Trewia nudiflora is one of the evergreen broad-leaved species, which often forms a dense homogenous forest. The leaves are large and broad in size and shape, which remarkably forms a dense canopy. The least FCD is covered by *Myrsine capitellata.* This is a small leaved shrub and never forms dense thicket. This analysis lead to a good correspondence between canopy dominant species composition and FCD. Further, ANOVA test showed that these forest types having corresponding mean canopy cover percentage statistically highly significance at P=<0.05 (Table 3). However, test failed to detect significance difference within each forest type because of some canopy

Table 3. ANOVA test for species composition.

ANOVA test					
	Sum of Sqares	df	Mean Square	F	Significance
Between Groups	9319.262	7	1331.323	3.321	**0.006**
Within Groups	17637.257	44	400.847		
Total	26956.519	51			

dominant species or forest types belongs very few sample plots. Importantly, FCD could be affected by biometry of forest such as forest types or species, morphological characteristics of tree and so on. Some species have broad leaves whereas others are coniferous. Broad leaves forest type definitely can make crown dense and closer hence canopy cover belongs in this type could be denser.

Forest products such as wood and fodder extraction are the major causes of deforestation and forest degradation in Chitwan (Schweik *et al.*, 2003). Nagendra (2002) also observed that the higher incidence of grazing, fire and tree lopping has occurred in the forest of Chitwan. Unlikely, some human disturbance such as coppicing is considered to be a canopy increasing factor in this analysis (Fig. 6 & 7). Because of its specific nature in some species, coppicing has capacity to increases forest canopy coverage. As revealed from the data debarking in site1 and girdling in site2 negatively affects the FCD. Although debarking and girdling kills tree slowly, it significantly affects the canopy density loss. However, debarking in site2 didn't affect on canopy alteration so the debarking could be recorded from the sample plots just few days or months later that interference has occurred. The relation of stumps with FCD in site1 is noticeably interesting. Possibly the stumps remain for long period in the ground and at the same time, the area could be covered by surrounding crowns (for more details on canopy dynamics see van der Meer, 1995). Finally, the nonparametric Kruskal-Wallis test has performed for significance test. However, only path (0.025) and fire (0.000) have executed significance at P=<0.05, but the test failed to detect significance for other variables.

5. Conclusion

FCD can be detected using multi-temporal remote sensing imagery, GIS, and FCD mapping technique. Pixel based forest canopy mapping with Landsat data is capable of consistently detecting the dynamic alterations of FCD. The results could be affected by setting threshold value in the process of FCD mapping. In case of canopy estimation in larger area, more field data with prior knowledge on image interpretation should be considered to overcome these problems.

It is concluded that site associated factors are closely related with alteration of FCD in the study area. Distance from human settlements observed to be most altering factor of FCD followed by rivers and roads. Based on this analysis, spatio-temporal dynamic alterations of FCD with mentioned site associated factors did not show the remarkable distinction. Therefore, to explain human dimension of environmental degradation in canopy is complex without detail analysis and understanding of the other additional factors.

So, the forest canopy is complex phenomena and could be affected by various factors. In this analysis we didn't cover all the factors that have possibilities to affect the forest canopy alteration. Detail study of additional factors such as biophysical (water streams distributions, soil type, altitude, slope & aspect, rainfall and temperature, etc.), physical (roads and trails, urban and settlement, other infrastructures etc.) and socioeconomic (demography, education, employment and economic status, types of energy use, energy consumption rate, institutional strengthening, status of NGOs and INGOs) factors and so on should be analyzed in a comprehensive way.

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