FOREST CANOPY DENSITY MONITORING, USING SATELLITE IMAGES

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ABSTRACT:

The increasing use of satellite Remote Sensing for civilian use has proved to be the most cost effective means of mapping and monitoring environmental changes in terms of vegetation and non-renewable resources, especially in developing countries. Data can be obtained as frequently as required to provide information for determination of quantitative and qualitative changes in terrain.
Forests as one part of the wild life of the human societies have a special place in economic development and stability of water and soil in the countries of the world. But because of various reasons such as development of population, increasingly changing forest to the other unsuitable applications such as: agriculture, providing energy and fuel, million of hectares from this natural resource are destroyed every year and the remainder of the surfaces change quantitatively and qualitatively. For better management of the forests, the change of forest area and rate of forest density should be investigated. It is possible that there isn't any change in the area of forest during the time but the density of forest canopy is changed. Therefore, in this research the method of Forest Canopy Density (FCD) monitoring that have been developed by other researcher is tested in an area, which is located in the north of Iran. This model calculates forest density using the four indexes of soil, shadow, thermal and vegetation. For this, the LANDSAT TM & ETM^+ images from different dates are used. At first, the forest density map was prepared by using Biophysical Spectral Response Modelling for two images. Overall accuracy 83% and kappa coefficient 0.78 for ETM+ 2002 image was achieved. Then, the changing of the area and forest density during these periods was distinguished.

1. INTRODUCTION

Satellite Remote sensing play a crucial role in determining, enhancing and monitoring the overall carrying capacity. The repetitive satellite remote sensing over various spatial and temporal scales offers the most economic means of assessing the environmental parameters and impact of the developmental processes. The anthropogenic intervention in the natural forest reduces the number of trees per unit area and canopy closure. Satellite remote sensing has played a pivotal role in generating information about forest cover, vegetation type and landuse changes. For better management of forest, changes of density should be considered. Forest canopy density is one of the most useful parameters to consider in the planning and implementation of rehabilitation program. Conventional methods for forest density estimation are:

1) Measurement with instruments (ground survey).

2) Aerial photo and satellite image interpretation

3) Satellite based method

Some of the disadvantages of measurement with instruments are time consuming and difficult to complete the revision in scheduled time. As a result, most of the stock maps do not reflect current status of forest.

Aerial photo interpretation method requires practice of studying aerial photographs under stereoscope and it is highly subjective.

Satellite based methods are conventional remote sensing method and biophysical response modelling. Different conventional remote sensing method such as slicing, image arithmetic, segmentation and multispectral image classification are prepared by different authors. One of the most complete of these methods is classification. Classification is based on qualitative analysis of information derived from "training areas" (i.e ground truthing or verification). This has certain disadvantages in terms of time and cost requirements for training area establishment. Also the similarity between spectral response of soil and low-density forest (in which background reflectance is so high), causes that spectral training data of classes to be overlapped with each other. Therefore, overall accuracy will be reduced.

In response to these problems, International Tropical Timber Organization (ITTO) developed a new methodology. In this new methodology, forest status is assessed on the basis of its canopy density. The methodologies called the Forest Canopy Density Mapping Model or in short the FCD model. In this investigation forest density map has been prepared for two different dates by FCD modelling and changes in forest density in different areas have been estimated.

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2. STUDY AREA

The study site covers the area of old growth forest plantation of north forest division of Iran. This area is within latitude 36 42 to 37 20 N and longitude of 49 10 to 49 59 E (Fig 1). The climate is wet and is characterize by high rainfall, high relative humidity and equable temperature.

Figure 1. Color composite (3, 2, 1) of the study area.

3. DATA

Three sets of TM & ETM+ of 1991, 1998 and 2002 were used in this study. The images were geometrically corrected. The control points were selected from common points recognizable on the ETM+ image and topographic map. The ETM+ image (2002) were corrected by 30 points using 2^{nd} degree polynomials (RMSE=0.34 pixel). 26 control points were selected on the ETM+, 1991 and 1998 image that by image to image registration,(using 2^{nd} degree polynomials), two images were corrected (RMSE=0.3&0.43). The pixels were resampled by the nearest neighbor method to maintain their original data.

4. METHODOLOGY

The digital image processing has been done using PC based of Intergraph package on Windows XP. In this investigation forest canopy density modelling has been prepared. The Forest Canopy Density model utilizes forest canopy density as an essential parameter for characterization of forest conditions. This model involves bio-spectral phenomenon modelling and analysis utilizing data derived from four indices.

- Advance Vegetation Index (AVI).
- Bare Soil Index (BI).
- Shadow Index or Scaled Shadow Index (SI, SSI).
- Thermal Index (TI).

Using this four indices the canopy density calculate in percentage for each pixel.

➢ Characteristics of Forest (4) Indices

The indices have some characteristics as below. The Forest Canopy Density Model combines data from the four (4) indices. Fig. 1 illustrates the relationship between forest conditions and the four indices (VI, BI, SI and TI). Vegetation index response to all of vegetation items such as the forest and the grassland. Advanced vegetation index AVI reacts sensitively for the vegetation quantity compared with NDVI. Shadow index increases as the forest density increases. Thermal index increase as the vegetation quantity increases. Black colored soil area shows a high temperature. Bare soil index increases as the bare soil exposure degrees of ground increase. These index values are calculated for every pixel. Fig. 2 shows the characteristics of four indices compared with forest condition.

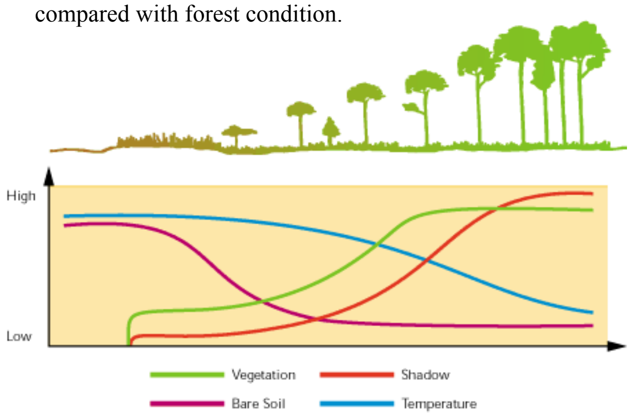

Figure 2. The Characteristics of four indices for forest condition

Note that as the FCD value increase there is a corresponding increase in the SI value. In other words, where there is more tree vegetation there is more shadow. Concurrently, if there is less bare soil (i.e. a lower BI value) there will be a corresponding decrease in the TI value. It should be noted that VI is "saturated" earlier than SI. This simply means that the maximum VI values that can be regardless of the density of the trees or forest. On the other hand, the SI values are primarily dependent on the amount of tall vegetation such as tree, which cast a significant shadow.

Table.1 shows combination characteristics between four indices.

	Hi-FCD	Low-FCD	Grass-Land	Bare Land
AVI	Hi	Mid	Hi	Low
BI	Low	Low	Low	Hi
SI	Hi	Mid	Low	Low
TI	Low	Mid	Mid	Hi

Table.1. Combination Characteristics between Four Indices

➢ Normalisation of Landsat TM Bands

The Landsat TM bands (except band 6) were normalized using linear transformation (equations 1 and 2).

$$A = \frac{(Y1\text{-}Y2)}{(X1\text{-}X2)} = \frac{20\text{-}220}{(M\text{-}2S) - (M\text{+}2S)} = \frac{50}{S} \quad (1)$$

$$B = -AX1 + Y1$$

$$Y = AX + B \quad (2)$$

Where: $X1=M-2S$ $X2=M+2S$ $Y1=20$ $Y2=220$

M=Mean S= Standard deviation

X= Original data Y= normalization data

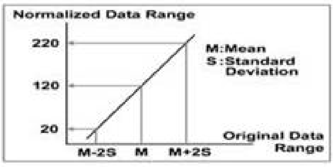

Figure 3. Normalization band data

- **Advanced vegetation index**

NDVI is unable to highlight subtle differences in canopy density. It has been found to improve by using power degree of the infrared response. The index thus calculated has been termed as advanced vegetation index (AVI). It has been more sensitive to forest density and physiognomic vegetation classes. AVI has been calculated using equation 3.

$$AVI = \{(B4 + 1)(256 - B3)(B4 - B3)\}^{1/3} \quad (3)$$
$$AVI = 0 \quad \text{If } B4 < B3 \text{ after normalization}$$

- **Bar Soil Index**

The bare soil areas, fallow lands, vegetation with marked background response are enhanced using this index. Similar to the concept of AVI, the bare soil index (BI) is a normalized index of the difference sums of two separating the vegetation with different background viz. completely bare, sparse canopy and dense canopy etc. BI has been calculated using equation 4 and 5.

$$BIO = \frac{(B5 + B3) - (B4 + B1)}{(B5 + B3) + (B4 + B1)} \quad (4)$$

$$BI = BIO * 100 + 100 \quad (5)$$

- **Canopy shadow Index**

The crown arrangement in the forest stand leads to shadow pattern affecting the spectral responses. The young even aged stands have low canopy shadow index (SI) compared to the mature natural forest stands. The later forest stands show flat and low spectral axis in comparison to that of the open area. SI has been calculated using equation 6.

$$SI = \sqrt[3]{(256 - B_1)(256 - B_2)(256 - B_3)} \quad (6)$$

- **Thermal Index (TI)**

Two (s) factors account for the relatively cool temperature inside a forest. One is the shielding effect of the forest canopy, which blocks and absorbs energy from the sun. The other is evaporation from the leaf surface, which mitigates warming. Formulation of the thermal index is based on this phenomenon. The source of thermal information is the infrared band of TM data (band6). The temperature data only has been used to separate soil and non-tree shadow. The color images produced from Landsat TM raw bands 4, 3, 2 and 5, 4, 3 provide valuable information on the forest cover type distribution. The normalization operation is not conducted for band 6 due to treatment of temperature calibration. The temperature calibration of the thermal infrared band into the value of ground temperature has been done using equation 7 and 8.

$$L = Lmin + ((Lmax - Lmin)/255) * Q \quad (7)$$

$$T = K2 / (\ln (K1/L + 1)) \quad (8)$$

Where L: value of radiance in thermal infrared.

T: ground temperature (k).

Q: digital record.

K1, K2: calibration coefficients.

K1=666.09 watts / (meter squared * ster* µm)
K2=1282.71 Kelvin
Lmin= 0.1238 watts / (meter squared * ster* µm)
Lmax= 1.500 watts / (meter squared * ster* µm)

- **The Procedure of FCD Model**

The flowchart of the procedure for FCD mapping model are illustrated in Fig.4. Image processed result corresponding to the flowchart shows in fig.3.

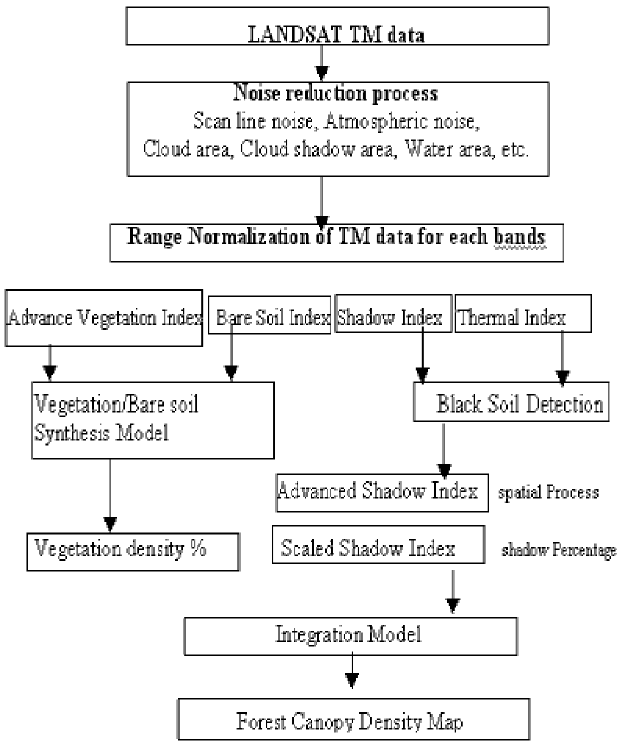

Figure 4. Flow chart of FCD Mapping Model

- **Vegetation Density; VD**

It is the procedure to synthesize VI and BI. Processing method is using principal component analysis. Because essentially, VI and BI have high correlation of negative. After that, set the scaling of zero percent point and a hundred percent point. Details in (A. Rikimaru, 1996)

- **Scaled Shadow Index; SSI**

The shadow index (SI) is a relative value. Its normalized value can be utilized for calculation with other parameters; The SSI was developed in order to integrate VI values and SI values. In areas where the SSI value is zero, this corresponds with forests that have the lowest shadow value (i.e.0%). In areas were the SSI value is 100, this corresponds with forests that have the highest possible shadow value (i.e.100%).SSI is obtained by linear transformation of SI. With development of the SSI one can now clearly differentiate between vegetation in the canopy and vegetation on the ground. This constitutes one of the major advantages of the new methods. It significantly improves the capability to provide more accurate result from data analysis than was possible in the past.

- **Integration process to achieve FCD model**

Integration of VD and SSI means transformation for forest canopy density value. Both parameter has dimension and has percentage scale unit of density. It is possible to synthesize both indices safely by means of corresponding scale and unit of each

$$FCD=\sqrt{VD*SSI+1}-1 \quad (9)$$

5. FOREST CANOPY DESITY MAP FOR STUDY AREA

The degree of forest density is expressed in percentages: 10% FCD, 20%, 30%, 40% and so on. The Fig.5 indicates forest canopy density map of the study area for ETM+ image.

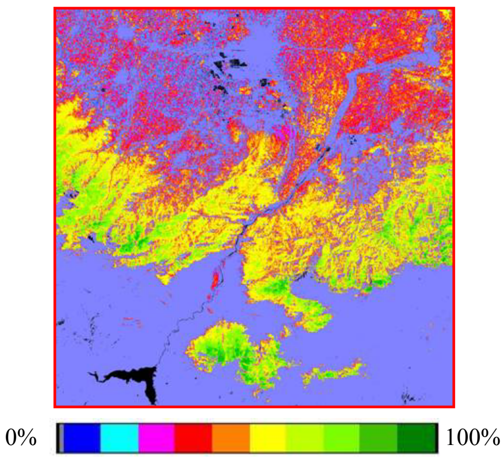

Figure 5. Forest canopy density map for ETM+ (2002).

For accuracy assessment and collected ground truth, the distance between classes were changes to the form below:

Class1) Water & Cloud =W&C

Class2) No Forest =NF (0-5%density)

Class3) Low Forest = LF (5-40%density)

Class4) Middle Forest =MF (41-70%density)

Class5) Dense Forest =DF (71-100%density)

Figure 6 indicates this map with these classes.

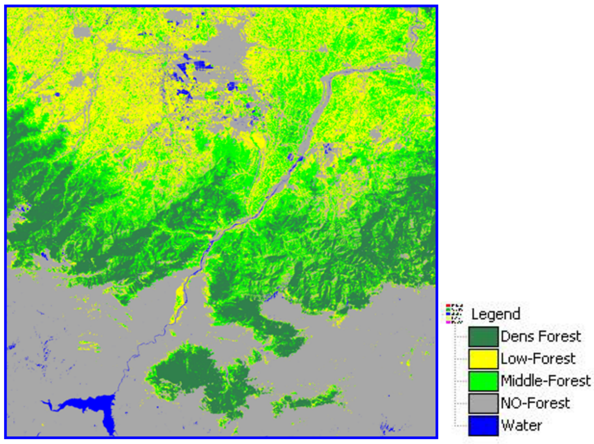

Figure6. 4 classes density map.

Table 2 shows the confusion matrix, overall accuracy and kappa coefficient, which is calculate for 2002 images.

	NF	LF	MF	DF	Total	U.A (%)
C1	10328	1622	18	0	11968	86
C2	273	8163	3311	3	11750	69
C3	9	246	6852	1227	8334	82.22
C4	0	0	127	8984	9111	98.61
Total	10610	10031	10308	10214	41163	41163
P.A %	97.34	81.38	66.47	87.96		

Table 2. Confusion matrix

Kappa Coefficient =0.78
Overall accuracy =83%

UA : User's accuracy   P A: Producer's accuracy

6. Forest density & Area changes in the studied site during 1991-1998

For change detection, the images should be taken at a simultaneous date and season also, they should be dereferencing exactly. Since the season for the 2002 image, differs from 1991, so we use 1998 and 1991 images. They have been dereferencing to 2002 image. Then we prepared density map, using these two images for the years 91 and 98. Fig 7 & 8 shows the forest density map for these years.

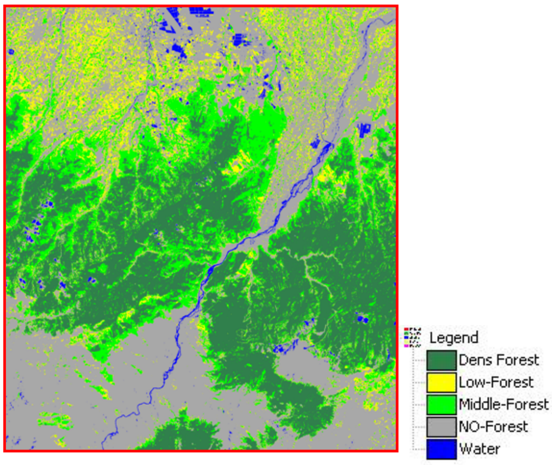

Figure7. Forest canopy density map 1991

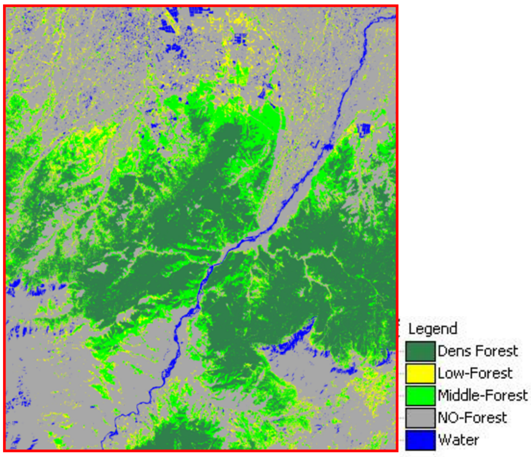

Figure 8. Forest canopy density map 1998

Pixel size at both dates is 28.5 m.

Since every map has 5 classes, 25 different case will happen in the changes map. 9 cases don't relative to the forest class changes. Totally, we will have 16 different cases for the forest changes, that the map below shows the forest canopy density changes at the two dates.

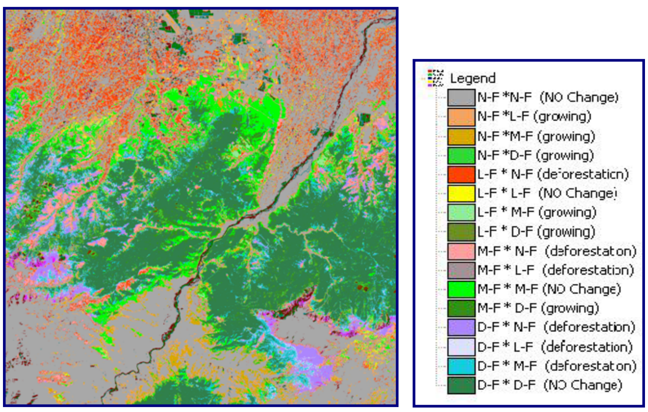

Figure 9. Forest canopy density changes during 91&98

The table 3 shows the rate of these changes.

Class in 91	Class in 98	changes	Number of pixel	Area changes (ha)
No Forest	No Forest	N-F--->N-F	990727	80471.80
No Forest	Low Forest	N-F--->L-F	88894	7220.41
No Forest	Middle Forest	N-F--->M-F	71510	5808.39
No Forest	Dense Forest	N-F--->D-F	20101	1632.70
Low Forest	No Forest	L-F--->N-F	231031	18765.49
Low Forest	Low Forest	L-F--->L-F	47030	3820.01
Low Forest	Middle Forest	L-F--->M-F	231031	18765.49
Low Forest	Dense Forest	L-F--->D-F	14701	1194.08
Middle Forest	No Forest	M-F--->N-F	165575	13448.82
Middle Forest	Low Forest	M-F--->L-F	68828	5590.55
Middle Forest	Middle Forest	M-F--->M-F	223747	18173.85
Middle Forest	Dense Forest	M-F--->D-F	126746	10294.94
Dense Forest	No Forest	D-F--->N-F	90420	7344.36
Dense Forest	Low Forest	D-F--->L-F	33751	2741.42
Dense Forest	Middle Forest	D-F--->M-F	136835	11114.42
Dense Forest	Dense Forest	D-F--->D-F	609326	49492.50

Table 3. The rate of forest canopy density changes during 91-98

NO Changes =151958 ha (59.39%)

Deforested =59005 ha (23.06%)

Growing = 44916 ha (17.55%)

7. CONCLUSIONS

Conventional RS methodology, as generally applied in forestry is based on qualitative analysis of information derived from "training areas" (i.e. ground-truth). This has certain disadvantages in terms of the time and cost required for training area establishment, as well as to ensure a high accuracy. Unlike the conventional qualitative method, the FCD model indicates the growth phenomena of forests by means of qualitative analysis. The accuracy of methodology is checked in field test. The case of Iran, the correlation coefficient value between FCD model and field check shows 0.83. It indicates higher correlation and accuracy compared to conventional remote sensing method. FCD model is very useful for monitoring and management with less ground truth survey.

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