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Full Length Research Paper

Forest crown closure assessment using multispectral satellite imagery

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Forest inventories have traditionally been used for acquiring quantitative and qualitative information of forests and for formulating management and conservation strategies of forests in Pakistan. It involves intensive and time consuming field surveys of rigid forest environments and entails high costs. However, with the advent of technology, remote sensing offers an alternative tool for acquiring forest data intended for forest mapping and consequently for effective forest management and monitoring. This research produces estimates for forest crown closure with SPOT 5 (2.5 m spatial resolution) and ALI (30 m spatial resolution) imageries. Ayubia National Park was selected as the study area for this research because the National Park has diverse varieties of coniferous and broadleaved tree species in their natural environment. Forest crown closure was assessed for each pixel of SPOT and ALI imageries by employing indices and principal component analysis. It was found that crown closure of Ayubia National Park generally falls between 45 and 65%. A comparison of results obtained from SPOT and ALI imagery was carried out. Accuracy assessment was obtained by using ground data of crown closure measurements.

Key words: Forest, crown closure (CC), SPOT, ALI, geographic information system (GIS), remote sensing.

INTRODUCTION

Crown closure (CC) is an important parameter in building a management strategy for a forest, and for formulating a work plan. In Pakistan, it is a general observation that the forests are depleting day by day. The reason behind this is that the area under forest remains the same, but, the density of the forest reduces and the gaps among canopies or crowns increase, resulting in depleting forests. Hence, it becomes important to measure the crown closure, rather than the area under forest, so that the change in forest cover over time can be effectively evaluated.

Crown closure plays a significant role in quantifying various bio-physical parameters such as photosynthesis, respiration, transpiration, CO^2 sequestration, land biomass and rainfall interception (Chen and Cihlar, 1996; Chen et al., 1999; Fassnacht et al., 1997; White et al., 1997). Moreover, the shape and size of a crown is an indicator of the tree health and shows the condition and rate of growth of the tree.

Remote sensing is a tool that provides reliable, up-to-date data of forests in less time, with low cost. This research studies and estimates forest crown closure by employing remote sensing and geographic information system (GIS), thus, supporting the nominal efforts that are taking place in providing an alternate source for collecting forest data in Pakistan.

Forest crown closure is a vital parameter being measured in forest inventory. It is a major factor in the evaluation of forest status and is an important indicator for changes in possible management strategies. For sustainable management of forests and protected lands, it becomes necessary to establish accurate and quicker methods of estimating forest crown closure. Traditional methods of measuring crown closure in field survey include the use of vertical sighting tubes, spherical densitometer and ocular measurements using formulae (Avery and Burkhart, 2002; Bonham, 1989). Stephens et al. (2007) quantified coarse woody debris and forest canopy cover in a pine-mixed conifer forest in north

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western Mexico. Moreover, Knowles et al. (1999) developed a canopy closure model using a digital camera to predict overstorey/understorey relationships in *Pinus radiate* silvopastoral systems. Canopy closure measurements have been used in a wide range of forestry applications. Johansson (1986) used vertical sighting tubes to measure canopy density in Scandinavian spruce and pine stands.

With the advent of technology, digital cameras and satellite imagery are now frequently used for assessing crown closure. St-Onge et al. (1997) carried out an automated forest structure mapping using high spatial resolution optical imagery. The author developed various regression equations for estimation of crown diameter, stand density and crown closure. Pignatti et al. (2008) used Hyperion imagery acquired over Pollino National Park, Italy, for mapping land cover, vegetation cover and vegetation diversity. Linear Spectral Unmixing technique was used for mapping land cover. Xu et al. (2003) assessed crown closure in Californoia, U.S, by using Landsat TM imagery for oakwood. The linear relationship between crown closure and DN values of each band of Landsat TM were examined.

Index based approach has been used by various scientists (Iqbal, 2011) to delineate surface soil salinity in the prime wheat-rice cropping area of Pakistan and to determine forest crown closure (Rikimaru et al., 2002) employing optical remote sensing in combination with Geographic Information System (GIS).

Jamalabad et al. (2003) applied remote sensing for assessing forest canopy density or canopy closure by applying a model. The model calculated Forest canopy closure using indices of soil, shadow and vegetation. For this purpose, Landsat TM and ETM+ images were used. Temporal analysis was carried out to determine the change in canopy density and area under forest. The same forest canopy density model was used by Hadi (2004) for estimating percentage of crown closures, which indicates the level of forest degradation and health in West Java, Indonesia. Azizi et al. (2008) also applied the same model for estimating forest canopy cover using IRS image in an old growth forest of north forest division of Iran.

This research focuses on application of GIS and remote sensing technologies for better management of forest of Ayubia National Park. Remote sensing and GIS are used as tools for quantifying forest crown closure as one of the parameters of forest inventory. Thus, the main objective of this study is to estimate forest crown closure of Ayubia National Park using SPOT and ALI imageries.

MATERIALS AND METHODS

Selection of study area

Ayubia National Park (ANP), Pakistan, was selected as the study area for this study. The reason for selecting the protected area of Ayubia National Park is given thus.

A diverse variety of tree species, that is, coniferous and broadleaved tree species are present in their natural environment in Ayubia National Park. The National Park is easily accessible from a number of towns, such as Rawalpindi and Abbottabad. Multi-spectral remote sensing data required for the study was available in the case of Ayubia National Park. The consensus view is that reduced density is the main cause of degradation in ANP (Rafi and Naqvi, 1999) as opposed to reduction in forest area and thus, an assessment of crown closure was essential.

The area of Ayubia is 33.12 km^2 (Rafi and Naqvi, 1999). The area of interest lies around an area center of 34.040 N and 73.410 S, the coordinates of upper left corner being 34.0630 N and 73.380 S, while that of lower right corner being 34.0160 N and 73.450 S.

Data obtainment

Traditionally, forest inventory is still undertaken in forests of Pakistan through intensive field surveys, which involves measurements through quadrats and transects for crown closure. This study involves methods that employ remote sensing and GIS technologies for estimation of crown closure in ANP. This method as per its accuracy and efficiency can overtake the primitive methods and thus efficiently assist in monitoring and managing forests in a sustainable manner.

The datasets used for this study are described thus. The satellite imageries used for this study are, SPOT multispectral imagery (2.5 m resolution), and ALI multispectral imagery (30 m resolution). The field data was collected by visiting sites in the field, measuring crown closure and determining coordinates with global positioning system (GPS). Survey was carried out for three days from 23rd to 25th May, 2008. Forest crown closure in field was measured by taking 12 random sample plots typically selected from Ayubia National Park.

The location of plots were recorded with GPS points and later overlaid and marked on SPOT and ALI images. The locations of plots are shown in Figure 1. Sample plot size was taken around 2500 m^2 to ensure inclusion of a pixel (30-m resolution) of ALI image. First, two cross-lines in directions along N-S and E-W were located with a 50 m measuring tape in the centre of a plot, in the field. The cross-lines were made approximately parallel to S-N and W-E directions. The length of intercepted parts vertically projected by crowns in canopies were then measured and summed. Finally, crown closure (%) was calculated by using the following formula (Avery and Burkhart, 2002; Bonham, 1989):

$$CC\,(\%) = \frac{\text{Sum of intercepted crown lengths}}{\text{Total line length}} \times 100$$

This data was used for verification of crown closure results derived from satellite images, through accuracy assessment. A scanned boundary map of ANP was obtained from World Wildlife Fund (WWF), Nathiagali. The boundary map was then digitized and used to extract the study satellite imagery.

Image processing

The SPOT and ALI images were preprocessed. Afterwards, the bands were normalized to make them available for further processing. For normalization of all the bands of an image, the raw data is first standardized. The standardized values are calculated by dividing the difference between the max raw values and a given raw value by the value range (Malczewski, 1997):

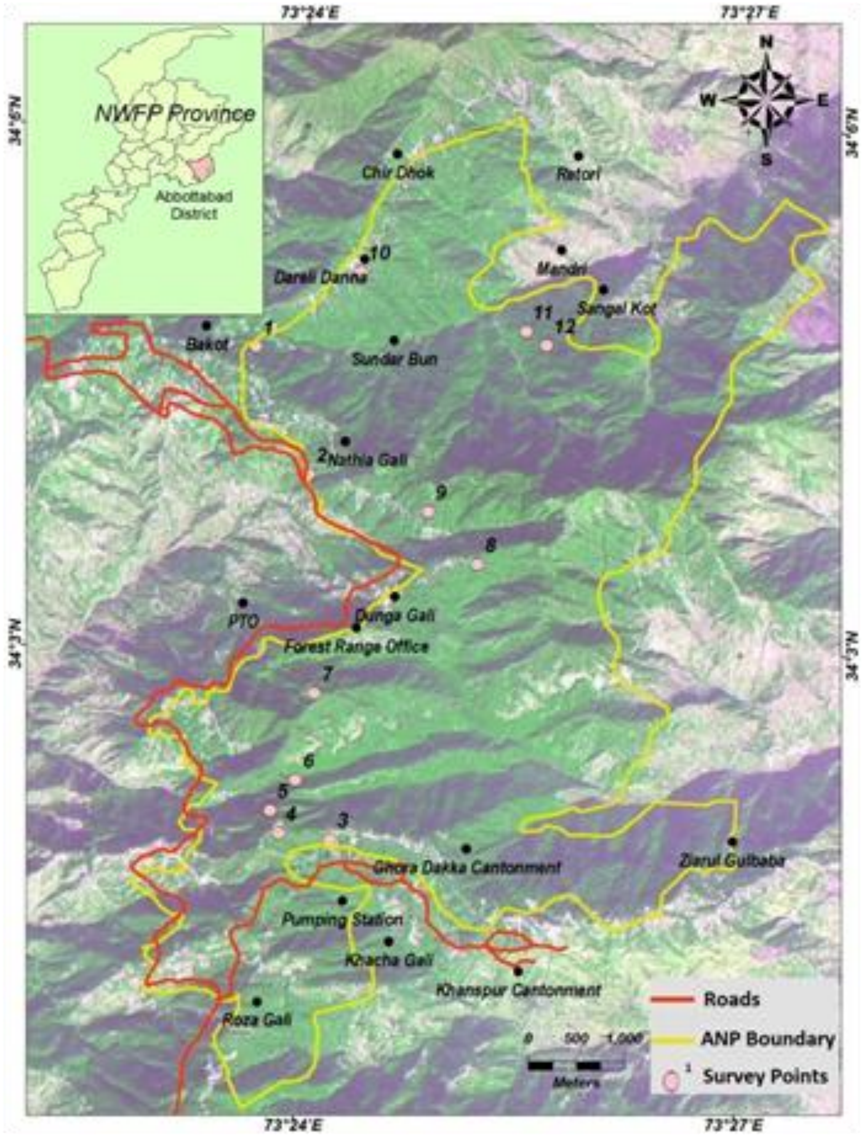

Figure 1. Satellite view (SPOT) of Ayubia National Park with its location, boundary, topographic features, road network, major villages and surveyed point locations.

X'yz= (Xymax – Xyz) / (Xymax – Xymin)

X'yz = Standardized value for the yth alternative and zth attribute; Xyz = raw value or original value; Xymax= maximum value for the zth attribute; Xymin= minimum value for the zth attribute.

The standardized data is used for the normalization of bands before further processing (Rikimaru, 1996; Rikimaru et al., 2002; Azizi et al., 2008; Jamalabad et al., 2003; Hadi et al., 2004):

Y = A Xyz + B

A = (Y1- Y2)/(X1-X2) = (Y1- Y2)/((M-2S)-(M+2S))

B = -AX1 + Y1

where X1= M-2S; M= mean; S = standard deviation; Xyz = original value; Y1 = maximum value of X'yz; Y2 = minimum value of X'yz; Y = normalization data.

Principal component analysis (PCA) transforms a multiband image into a more interpretable image by compressing similar data. PCA was invented in 1901 by Karl Pearson. Now, it is mostly used as a tool in exploratory data analysis and for making predictive models (Chen et al., 2011). In this study, PCA is used for scaling of data.

Forest crown closure or forest canopy density is an essential indicator of forest condition and health. A model was developed by Atsushi Rikimaru during International Tropical Timber Organization (ITTO) project, 1995, for calculating forest canopy density or crown closure. The model is also known as Rikimaru's model or Rikimaru's approach (Rikimaru et al., 2002; Hadi et al., 2004; Roy et al., 1996). This model was developed for providing a simple methodology for monitoring and management of forests. The model indicates that a relationship exists between crown closure and the dynamics of forest ecology. This approach takes into account the forest crown closure as an important indicator of forest condition. Unlike the conventional qualitative method, this model indicates the

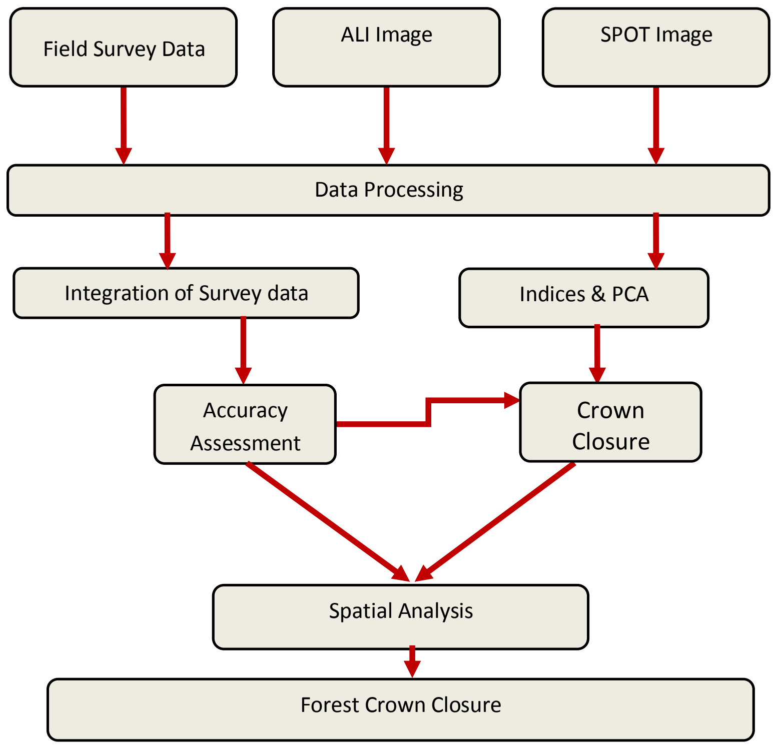

Figure 2. Methodological chart of the study, showing the data processing of field survey data and satellite data ultimately resulting into estimation of forest crown closure.

growth phenomena of forests, which is a quantitative analysis. The canopy density is calculated in percentage for each pixel. Three indices, that is, advanced vegetation index (AVI), bare Soil Index (BI) and shadow index or scaled shadow index (SI, SSI) are used in this model for estimating forest crown closure (Rikimaru et al., 2002). These index values are calculated for each pixel in the image.

Models selected

The models that were selected for this research are described further.

Advanced vegetation index (AVI)

Vegetation indices are mathematical or statistical combinations of spectral bands that enhance the differences between vegetation reflectance and that of other materials like soil. A good vegetation index is sensitive to the amount of vegetation, differentiates vegetation from soil and reduces the difference between radiance and reflectance caused by the atmosphere. AVI is regarded more beneficial for estimating canopy density as compared to NDVI that is not capable of highlighting slight changes in the canopy density. Thus, AVI is more sensitive to quantitative analysis of vegetation (Azizi et al., 2008). Anonymous (1993) suggested that improvement in the examination of slight changes in canopy density can be achieved by using power degree of the infrared response. Thus, AVI uses the power degree of the infrared response in the formula given below (Roy et al., 1996):

AVI = [(IR +1) (256-R) (IR-R)]1/3

AVI = 0 If IR<R after normalization

For ALI imagery, the following band combinations were used:

AVI = [(B6 +1) (256-B4) (B6-B4)]1/3

For SPOT imagery the following band combinations were used: AVI = [(B3 +1) (256-B2) (B3-B2)]1/3

Baresoil index (BI)

Bare soil index separates bare and barren land from vegetation, thus making it possible to distinguish sparse vegetation having gaps from dense vegetation areas. In case vegetation cover is less than half of the total area, the results obtained from advanced vegetation index are unreliable. Thus, for better results, a combination of AVI and BI are used to assess the actual status of vegetation in the area. The principle of obtaining vegetation status is based on the higher response between vegetation and baresoil status. Therefore, forestlands can be evaluated by the combination of AVI and BI indices. The formula for calculating bare soil index for ALI and SPOT imagery respectively are given as:

BIO= (B7+B4)–(B6+B1) / (B7+B4)+(B6 + B1)
(For ALI Imagery)

BIO= (B4+B2)–(B3+B1)/(B4+B2)+(B3+B1)
(For SPOT Imagery)

BI = BIO*100 +100

Shadow index (SI)

Shadow index is directly proportional to the vegetation density. Forest canopies vary markedly with species composition, age and succession stages. The variations in forest canopies produce differences in the amount of shadow present in the forest affecting reflectance values. Pronounced shadows are developed by tall trees forming a crown arrangement pattern, thus producing changes in the spectral responses of forest areas. Natural forests have high values of shadow index as compared to young planted vegetation. The shadow index is calculated by utilizing low radiance visible bands. The formula is:

SI = ((256-B2)(256 – B3)(256 – B4))1/3

Scaled shadow index (SSI)

Scaled shadow index (SSI) enhances the spectral differences between mature forests that have higher canopy shadow index value compared with that of younger forest stands. Shadow index (SI) is a relative value. This value cannot be integrated with other parameters unless normalized.

For integration of AVI and SI, SSI was developed. Hence, SSI is a normalized form of SI, where value of zero indicates lowest shadow area (0%) and value of 100 corresponds to the highest shadow area (100%). The value range of SI is scaled from 0 to 100 in SSI. This linear transformation or scaling of SI is carried out by principal component analysis**.**

Vegetation density (VD)

VD is an intermediate step used in calculating the ultimate forest crown closure through a specified formula. VD is obtained by the synthesis of AVI and BI using principal component analysis. As AVI and BI have high correlation of negative values, principal component analysis scales the value range from zero percent to hundred percent. In this way, both AVI and BI are integrated as well as scaled.

Forest crown closure (FCC)

FCC model also has the capacity to incorporate a thermal index to separate soil, particularly burn scars, from shadow other than that cast by trees. But the thermal index was not incorporated in this study as both SPOT and ALI imageries are devoid of thermal bands. Forest crown closure is achieved in percentage by integrating VD and SSI.

Tall tree vegetation is a source of producing more shadow thus increasing SI values. Thus, the increase in forest crown closure would result in the subsequent increase in shadow and SI values. FCC is calculated through following formula (Rikimaru, 1996; Rikimaru et al., 2002; Azizi et al., 2008; Jamalabad et al., 2003; Hadi et al., 2004):

FCC= (VD*SSI +1) ½ −1

RESULTS AND DISCUSSION

Forest crown closure was estimated through satellite imageries utilizing indices through raster calculator included in the Spatial Analyst Tool in ArcGIS.

AVI

Advanced vegetation index was applied on SPOT and ALI imagery for highlighting vegetation areas. The area is mainly composed of forests, as it is regarded as a protected area (Rafi and Naqvi, 1999). Therefore, most of the area showed high values of AVI on both SPOT and ALI imageries depicting area rich in vegetation. Figure 2a and b shows the AVI maps for SPOT and ALI.

BI, SI and SSI

Bare soil index extracts areas having bare soil and thus helps in observing vegetation with gaps, providing us information about dense and sparse vegetation areas. Bare soil index applied on SPOT imagery of Ayubia National Park is shown in Figure 3c.

The high values of bare soil occupy a small area of Ayubia National Park and are in fact due to landsliding activity at steep slopes. BI results of SPOT and ALI are similar, indicating minimum presence of bare soil in the area shown in Figure 2c and d, respectively. The occurrence of shadow in an image mainly depends upon the topography and terrain of the area. Mountains and tall tree crowns cast shadow on ground surface, thus giving a darker tone of the area on satellite imageries. SI highlighted shadowed areas on SPOT and ALI imageries are shown in Figure 3a and b, respectively.

FD

Forest density index is derived by the synthesis of advanced vegetation index and bare soil index. The two indices are integrated together using principal component analysis. The FD index shows the density of forest cover. FD index was calculated for SPOT and ALI imagery. Forest density maps generated from SPOT and ALI imageries are shown in Figure 3c and d, respectively.

FCC

Forest crown closure percentage for each pixel of SPOT and ALI imagery was calculated for the study area. Two resultant maps were generated for SPOT and ALI imagery; one for general purpose, convenient for foresters having 5 classes, whereas, second map was generated for viewing the minute details of differences in crown closure having 20 classes. Figure 4a and b shows the forest crown closure maps generated from SPOT, whereas, Figure 4c and d shows the resultant maps from ALI imagery.

The results from SPOT show that crown closure generally falls between 20 and 65% in the study area. The maximum area lies under crown closure class 55 to 60% and 60 to 65%. The greatest part of study area lies

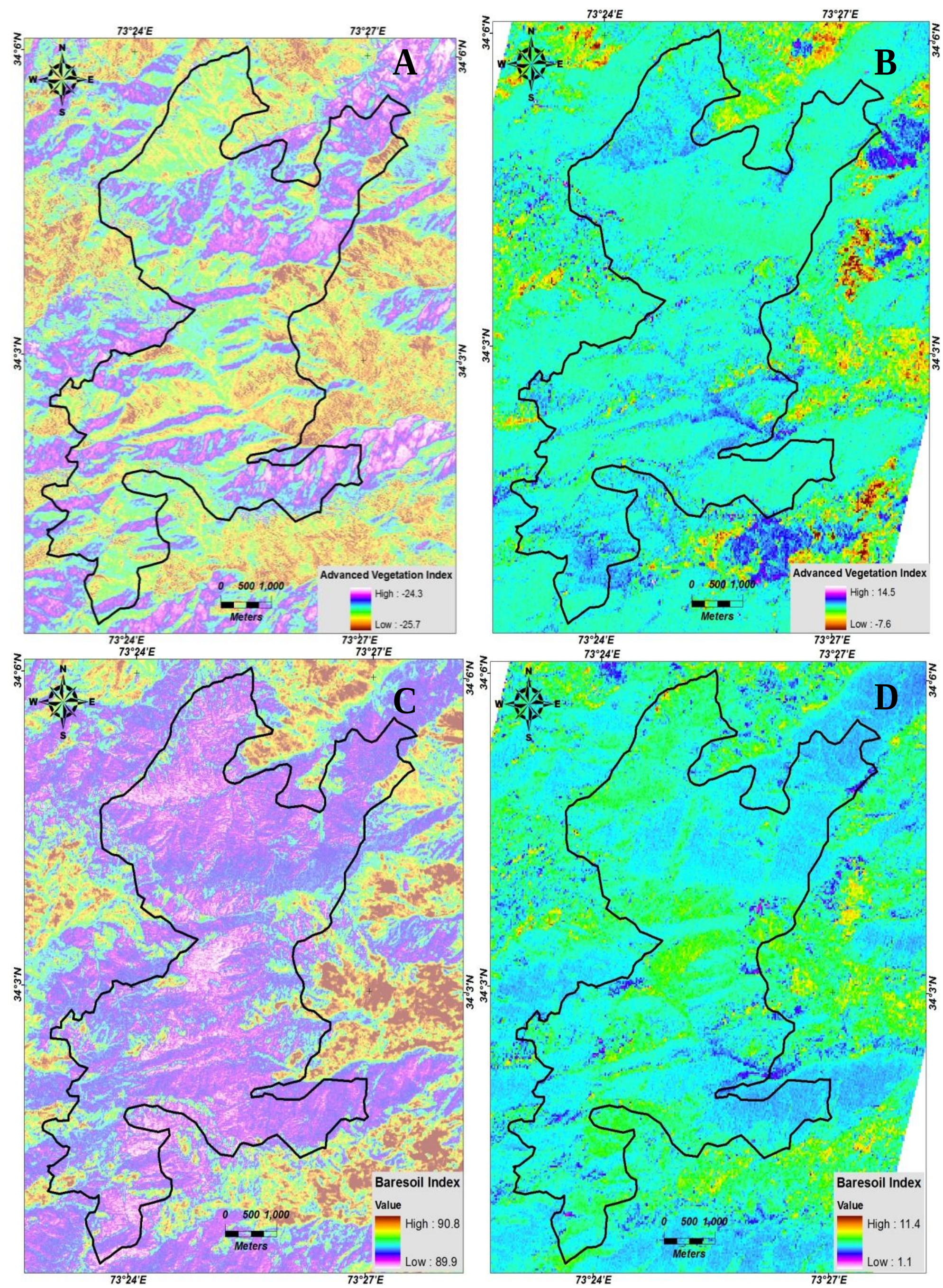

Figure 2. Advanced vegetation index (a and b) and baresoil index (c and d) maps of ANP, Abbottabad District, Pakistan, derived from SPOT and ALI data. AVI is showing high values in the study area depicting area rich in vegetation. High values of BI lie outside the boundary of ANP indicating less bare soil in ANP.

under 25 to 75% CC, covering an area of 22.24 km^2, the total study area being 33.95 km^2. Ayubia National Park is a protected area, but still under various pressures. The trees are being cut by local population as well as timber mafia, reducing the crown closure of the forest, but the area under forest remains the same. An area of 0.07 km^2 lies under CC below 25%, 5.26 km^2 area lies above CC 75%. Overlay analysis showed that the area above CC 75% is actually the builtup area and landslide area giving high values of CC %. The method applied was unable to detect the builtup area and landslide area. Therefore, maximum CC % in the study area derived is 75%.

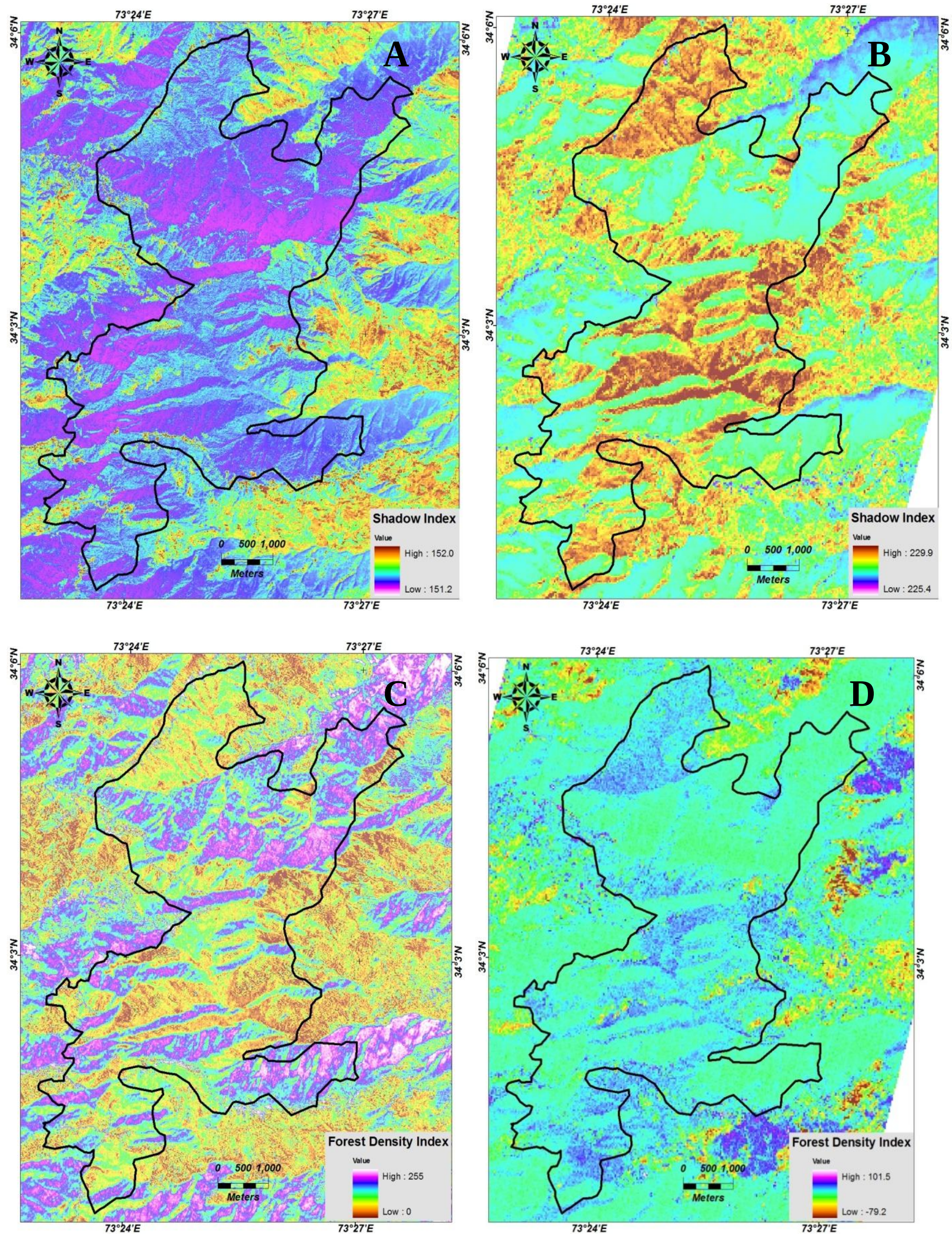

Figure 3. Shadow index (a and b) and forest density (c and d) maps of ANP, Abbottabad District, Pakistan, derived from SPOT and ALI data. High values of SI highlights the shadowed areas, whereas, FD maps shows that steep terrain areas have low vegetation cover and high shadow values.

Some areas of Nathiagali and DungaGali showed higher CC of 45 to 75%, whereas, some areas showed 20 to 40% CC. The area of Dareli Danna showed high CC of 55 to 65%. GhoraDhakka also showed high CC values of 40 to 75%. SangalKot showed a wide range of variation in CC from 20 to 60%. Hence, high CC % lies in areas of Dareli Danna, GhoraDhakka, some parts of Nathiagaliand DungaGali, whereas, lower CC value of 20% lies in area East of Nathiagali. These locations are marked in Figure 1 and can be identified from the map.

The results from ALI imagery show that crown closure generally falls between 45 and 65% in the study area.

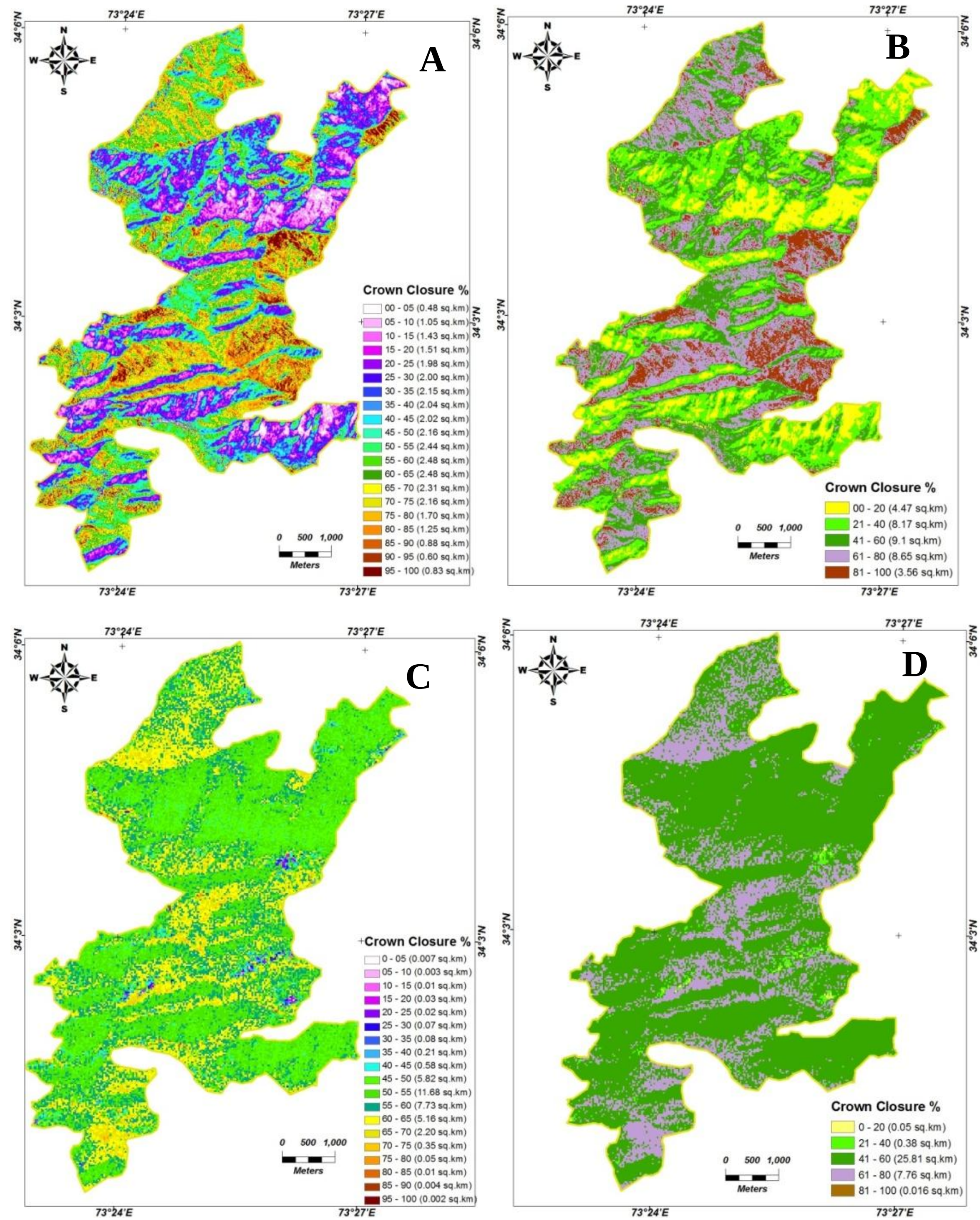

Figure 4. Forest crown closure of Ayubia National Park derived from SPOT (a and b) and ALI (c and d) imageries, expressed in 20 classes and 5 classes, respectively. The maps show that crown closure generally falls between 20% and 65% in SPOT, whereas, 45 to 65% in ALI.

Most of the area lies under classes ranging in percentage from 45 to 65% (30.39 km^2) with a maximum at 50 to 55%. The remaining classes occupy only 3.62 km^2, making a total area of 34.02 km^2 in case of ALI imagery.

An area of 0.36 km^2, lying under CC of 40% and below, shown in blue color in Figure 4c, is builtup or landslide area. Thus, minimum CC in these areas shows that the results are correct.

Nathiagali and Dunga Gali were found to have a CC of 60 to 65% through ALI imagery. Dareli Danna and Sundar Bun showed high CC values of 65 o 70%. Sangal Kot area was found to have a CC of 50 to 55%. The areas East of Nathiagali showed a CC of 45 to 55%. Hence, high CC% lies in areas of Dareli Danna, Sundar Bun, Nathiagali, Dunga Gali and Sangal Kot, whereas, low CC % was found in builtup and landslide areas.

The results show that the areas detected in SPOT imagery as 20% CC lying East of Nathiagali showed 45 to 55% results on ALI imagery. Moreover, ALI imagery was able to detect the landslide and builtup areas as low CC % areas, whereas, SPOT imagery gave high CC % for such areas and was unable to identify the builtup area and landslide area.

Thus, it is concluded that unless the spatial resolution of a satellite image is high, it will give generalized results for CC, even if it has high spectral resolution. The maximum area lies under crown closure classes ranging from 55 to 65% in SPOT, whereas, 50 to 55% in ALI.

Model assessment

The samples collected in the field for measurement of crown closure were used as reference for accuracy assessment. The points taken on ground were distributed into CC classes. Overall Accuracy and Kappa Statistic for SPOT and ALI imagery was then computed. SPOT showed overall accuracy of 75% whereas, ALI showed 58%. Kappa statistics was calculated, which showed 70% results for SPOT and 51% for ALI imagery. It was concluded that SPOT imagery showed better results than ALI imagery for CC measurement of Ayubia National Park.

Conclusion

Forest crown closure was achieved using SPOT and ALI imagery for each pixel. It was found that crown closure of Ayubia National Park generally falls between 20 and 65% with reference to SPOT imagery and 45 and 65% with reference to ALI imagery. Moreover, the results show that the greatest value for crown closure derived from SPOT and ALI imagery is 75%, whereas, the maximum area lies under crown closure 45 to 65%.

It is concluded that SPOT imagery gave better results as compared to ALI imagery for crown closure assessment, as SPOT imagery captured intricate details of lower classes of crown closure due to its higher spatial resolution, which were not evident in the results of ALI imagery. The reason is that SPOT imagery has high spatial resolution of 2.5 m, whereas ALI has spatial resolution of 30 m, and thus was unable to capture intricate details. ALI imagery has high spectral resolution as compared to SPOT imagery, but the greater spectral resolution alone was not suffice for the study. Thus, it is concluded that unless the spatial resolution of a satellite image is not high, it will give generalized results for CC, even if it has high spectral resolution.

Although SPOT imagery gave intricate details and better results as compared to ALI imagery, nevertheless, SPOT was unable to detect the builtup and landslide areas and gave them high CC% values, whereas, ALI imagery was able to detect the builtup and Landslide area assigning them low CC% values.

This study can be used as a basis for further estimation of crown closure of Murree and Galiat Forests having similar climatic, edaphic and zonal characteristics. Moreover, this study can efficiently assist the Forest Department and WWF Department in managing the protected area of Ayubia National Park.

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