

COMPARATIVE EVALUATION OF DIFFERENT SPATIAL RESOLUTION DATA FOR TIMBER VOLUME ESTIMATION

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ABSTRACT:

This study compares the data available from different satellites having different spatial resolutions to estimate the timber volume. The study comprises mainly the stratification of forest from the input of classified satellite data, measurement of timber volume in the field, extraction of the pixel information for the plots, preparation of a continuous volume map and its comparison among different outputs. Regarding this study, the image processing in the study consists of two phases i.e. Pre Processing and Post Processing. The sample size for the strata has been determined analysing the variance of timber volume within strata which was assessed with the Pilot Inventory prior to the final forest measurement. The field measured plot-wise timber volume, extracted pixel information; stratification information and the geographical information have been tabulated and were analysed with regression analysis to find the best-fit regression equations in all sets of data. All PAN sharpened including LISS III MSS subset images have been multiplied by corresponding best-fit linear regression equations to prepare the continuous volume maps. The contribution of remote sensing data for timber volume estimation has been compared with respect to the R-Square values obtained from the regression analysis in other way. The study concludes that there is not only the effect of spatial resolution on the estimation of timber volume but also the spectral resolution of satellite data seems to have contributed more because the distortion produced by PAN sharpening of the image deteriorates the interpretability of the image.

1. INTRODUCTION

The forest has a great role in human life. It has not only to provide goods for consumption but it also has an ecological, environmental and aesthetic role in human life. Current trend of forest management is not only focused on the utilitarian concept but rather focuses on the perspective of the environmental protection, assessing the forest parameter timber volume is still an essential parameter during forest assessment.

Sustainable forest management is defined as a multidisciplinary task, requiring collaboration between government agencies, non governmental agencies (NGOs), and people, especially rural people to ensure that the goods and services derived from the forest meet present-day needs while at the same time securing their continued availability and contribution to long-term development (FAO, Sustainable Forest Management). Thus we can say that the sustainable forest management should cover both the objective of social need fulfilment and the ecological balance. A Canadian Approach to Criteria and Indicators (C&I) of Sustainable forest management in boreal and temperate forest consists total of 85 criteria and indicators

of sustainable forest management. Out of 85 C&I Goodenough *et al.* (1998) suggested that 22 indicators could be addressed partially or fully by remote sensing as well as GIS technology.

Growing stock estimation is an important parameter required for forest management and planning (Mahto 2001) and stock per unit area is the key information desired for forest inventory (Singh and Roy, 1990). Tomppo (1993) stated in his study "remote sensing is a cost efficient source of information for large-area forest inventories and satellite image data has been widely applied in various inventory tasks". Multisource NFI has introduced in Finland combined the field measurement of sample plots, digital image information and numerical map and elevation data by means of nonparametric image analysis (Makela and Pekkarinen, 2001).

Remote sensing and GIS provide for the continuous monitoring of forest developments by detecting changes and for the integration of the results into existing databases (Sustainable Development, 1999). As the plantation may have homogenous blocks of the different age group and tree species which allow identifying the features more easily and prominently than in complexities of natural stand. Forest management requires

more information about the extent, composition, density, age variation and trends in the plantation forestry (Hock *et al.*, 1998). There are two categories while analysing the remote sensing data for the application of assessing the forest parameters. One is “How to relate pixel values across an image to locally-known ground values by using statistical techniques?” and other one is the attempt to recognize the items of interest on the image (Hock *et al.*, 1998). The Kyoto protocol defined the use of remote sensing in five different areas. Amongst them, Art-3 describes the application of remote sensing for quantification of aboveground vegetation biomass stocks and associated changes (Rosenqvist *et al.* (Ed.), 1999). Franklin (1986) and Peterson and Nilson (1993) stated that the correlation between spectral data and volume is stronger for younger stands than for older (Reese *et al.*, 2002).

The global trend of forest resource management is related to the level of carbon sequestration through the documentation of contribution of the individual country to the global carbon sequestration scenario. There is strong argument among the developed and developing countries: “who are contributing more to the global scenario of carbon sequestration?” The remote sensing data were being used for the purpose of stratification after the classification of image. Jakkola (1986) mentioned in the paper that remote sensing by satellites is a method of measurement for the forest manager and planner, which is subject to some error. Remote sensing is a powerful tool for rationalization of information acquisition in forestry if it is used in the right way for the right purpose (Jakkola, 1986). The use of PAN sharpened image gives better interpretability of the high spatial resolution data getting the spectral information from low resolution. The use of PAN sharpened image is better than design new sensor (Leung *et al.*, 2001).

2. STUDY AREA

The study area is located geographically within the range of latitude 3359474.38 m and 3360993.51 m and longitude 211453.24 m and 213160.64 m within the Forest Research Institute (FRI) in Dehradun of Uttaranchal State in India. The area consists majority plantation of *Pinus roxburghii* (Chir Pine), *Tectona grandis* (Teak), *Eucalyptus* spp and *Dendrocalamus strictus* (Bamboo), coppice stand of *Shorea robusta* (Sal) and the small stand of mixed natural as well as planted species i.e. *Mesua ferrea* (Iron wood), *Agathis robusta*, *Michelia champaca* (Champ), *Mallotus philippinensis* (Rohini) etc.

3. MATERIALS

Satellite data

There are four sets of data, which have been used for this study i.e. IKONOS MSS and PAN, IRS 1D LISS III and PAN, Landsat ETM+ MSS and PAN, and LISS III alone.

Field measured Volume data

The forest volume attribute data obtained from the field by forest cruising using classified images and sampling techniques. Two-stage sampling was adopted, that is satellite data in one stage and field sampling in the second. Stratified random sampling technique is used for forest sampling. The measurements of individual trees are summed as total volume for the plot. The measured data is extrapolated to find the growing stock per hectare in each sample plot.

Softwares

ERDAS IMAGINE 8.6 and eCognition 3.0 GIS and remote sensing softwares have used for image analysis and object oriented classification respectively and SPSS 11.0 a statistical software has used for regression analysis.

4. METHOD

Image Processing

IKONOS multispectral data, IRS 1D LISS III data and Landsat ETM+ data have been stacked separately to get RGB images for better visualization. Thus, all satellite data have been registered in Universal Transverse Mercator System (UTM) with the WGS 84 spheroid. Using PCA merging technique and nearest neighbour resampling technique multispectral images have merged with its own Panchromatic image with higher resolution to get multispectral image with high resolution i.e. IKONOS multispectral data with IKONOS Panchromatic image and so on. The study area covering the forest within FRI was extracted in all sets of data whether it is plantation or natural trees with the aim of making a classification of the forest easy. The study area covers approximately 165 ha. The interested area from the image has been extracted by the operation of subsetting the image by laying over the polygon of Area of Interest (AOI).

Classification

The characteristic for the object-oriented approach of image classification is circular interplay between processing and classifying image objects. Some specific information is available for classification based on segmentation, scale and shape of image objects. Segmentation of the image is the basis for the object-oriented classification of the image. It segments the image in objects by grouping the similar pixels within the limit of a certain criterion. There are two main criteria, one is Heterogeneity criterion i.e. scale parameter and other is the Homogeneity criterion i.e. colour and shape and within shape

also smoothness and compactness. The classification based on the object-oriented approach consists of the automation of the classification and the use of an expert knowledge base. The expert knowledge bases have been extracted from the knowledge of the expert/investigator, which is the knowledge of the field. The first field visit was carried out with the hardcopy IKONOS PAN image to identify major forest type within study area. During these field verifications the GPS reading was taken where it was possible within the study area.

The segmented images were classified based on the different criteria by using the nearest neighbour technique, with which the objects were classified based on the surroundings with the input of samples from the field knowledge. In this study the classification was only based on the forest plantation type. Thus the classified images were a forest type map of study area. After the *Nearest Neighbour* classification of the segmented images with sample input, the result was refined by using the *manual classification* because the classification was not satisfactory, which can be seen visually and also tallied with the field knowledge.

Stratification

On the basis of classified image (Forest type map), the entire forest was stratified in different homogenous strata according to forest type. The aim of the stratification is to enhance the accuracy of the timber volume estimation in a heterogeneous forest by dividing into different homogenous strata. Thus the timber volume will be extrapolated for each stratum, since the field data have been measured by taking consideration of the forest stratification. The measurement of the forest was divided into two parts; first the Pilot Inventory for the purpose of variance analysis within the stratum and second the final timber measurement of the forest. For the pilot inventory, 5 plots in each stratum have been selected randomly and inventoried in the field. In this field measurement also GPS reading were taken where it was possible to read mainly of the plot centres. The additional sample plots were randomly selected within stratum and inventoried in the field. The forest parameters: tree height and dbh were measured in the same manner as the pilot inventory.

Analysis of Variance and standard deviation

The measured values in each of the five plots have been added and analysed with respect to the variance as well as the standard deviation within each stratum. The variance tells about the sample plot's volume variations. The variance and the standard deviation have been calculated by using the following formulae,

$$S_j^2 = \frac{1}{n(n-1)} [n \sum_{i=0}^n x_i^2 - (\sum_{i=0}^n x_i)^2] \quad (1)$$

$$S_x^2 = \frac{1}{N} \sum_{j=1}^m [\frac{N_j^2 S_j^2}{n_j} - (\frac{N_j - n_j}{N_j})] \quad (2)$$

Stratified Random Sampling

The stratified random sampling technique was applied for the extraction of field measured timber volumes. The optimum allocation of sample plots were carried out to allocate the sample plots among strata..

$$n_{st} = \frac{(\sum N_h S_h)^2}{N^2 D^2 + \sum N_h S_h^2} \quad (3)$$

(Freese, F. 1962)

Where,

n_{st} = Number of sample plots in stratum

N_h = Area of stratum h

S_h = Standard deviation within stratum h

N = Summation of N_h

D = Desired size of the Standard error of the mean

$(\sum N_h S_h)^2$ = Square of Summation of product of area of strata and the standard deviation on estimates

$\sum N_h S_h^2$ = Summation of the product of area of strata and the square of standard deviation on estimates

For the purpose of the study the value of D is taken as 1 with the indifferent value of standard error.

Estimating timber Volume

Local and General volume equations, adopted from the Forest Survey of India (FSI), were used to calculate timber volume by tree. By means of statistical calculations the total timber volume was estimated for the entire forest. Summing up all individual trees gave the total timber volume existing within the sample plots. The summed timber volume in each sample plot has been calculated in terms of volume in cubic meter (m^3) per hectare. The average timber volume per hectare in each stratum has been calculated by averaging from the samples within the stratum. Then, per hectare timber volume in each stratum has been extrapolated in terms of total timber volume in each stratum by multiplying by the area of the stratum. The

operational formulas for all computation of statistical means are as follows (Cochran, 1977):

$$V_{sp} = \sum_{i=0}^n V_i \quad (4)$$

$$V_{ph} = \frac{V_{sp} * 10000}{a} \quad (5)$$

$$\bar{V}_{st} = \frac{\sum_{i=1}^n V_{ph,i}}{n} \quad (6)$$

$$V_{st} = \bar{V}_{st,i} * A_{st,i} \quad (7)$$

Where

V_i = Volume of single tree

V_{sp} = Total timber volume within sample plot

V_{ph} = Timber volume per hector

\bar{V}_{st} = Average per hector timber volume within stratum

V_{st} = Total timber volume within stratum

a = Area under the sample plot

Pixel information

The spectral information of pixel had extracted by using diamond shaped window by the mimic of sample plot shape and size depending on the resolution of the image. To find the relationship between remotely sensed data and timber volume, the pixel information for the sample plots and timber volume from the field measurement were regressed each other. The stepwise entering regression analysis has carried out treating as the timber volume dependent variable and layer wise pixel information and strata information as independent variables.

The analysis has been examined by doing separately in whole sample points, all sample points with strata information, pine sample only, other than pine samples and square root function of timber volume. The regression coefficients, Adjusted R-Square and R-Square values of all set of data have been considered for the study. The best fit linear regression equations for the prediction of timber volume have been selected by comparison of R-Square values.

Preparation of the continuous volume map

The continuous volume maps of the study area were prepared by using the linear regression equations and the original image. During the preparation of the continuous map the timber

volume has been categorized in 8 classes i.e. volume with 8 classes in the interval of 20 cubic meter timber volume.

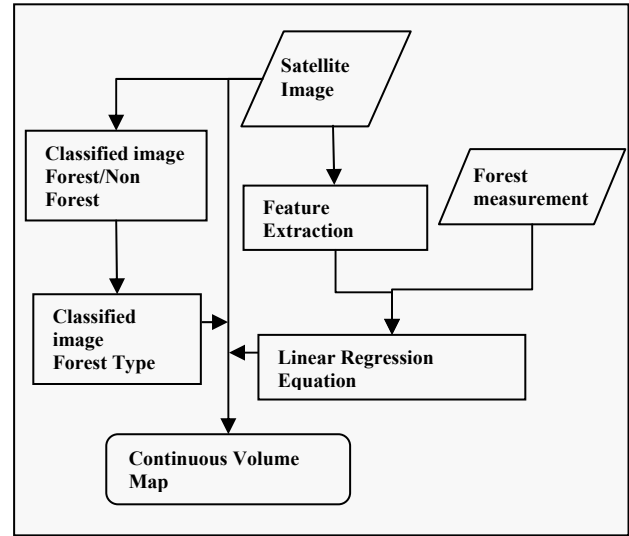


Figure 1 Process of Volume map preparation

5. RESULTS AND DISCUSSIONS

Results

Classified Outputs

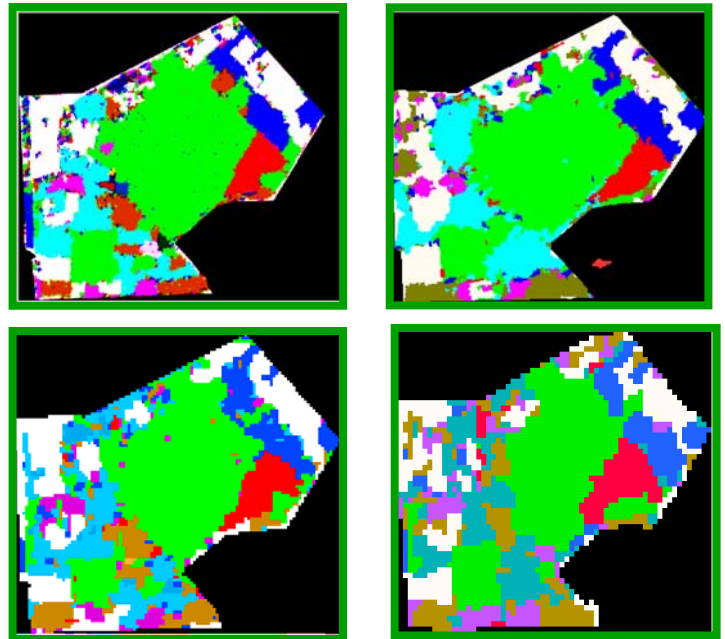


Fig. 2 Classified images for the support of Forest Type Map

Classification data table

Class	IKONOS merged	LISS III & PAN merged	ETM merged	LISS III
<i>Dendrocalamus strictus</i>	4.5	5.0	6.9	9.0
<i>Eucalyptus</i>	14.8	14.0	14.5	14.0
<i>Miscellaneous</i>	18.2	25.0	23.5	26.0
<i>Pinus roxburghii</i>	68.0	64.0	63.0	56.0
<i>Shorea robusta</i>	7.6	7.0	8.8	9.0
<i>Tectona grandis</i>	16.3	14.0	14.1	20.0
<i>Unclassified</i>	31.8	34.6	33.5	30.0
<i>Other Species</i>	3.6	--	--	--
Total	165	164	164.21	164.0

Table-1 Area covered by different class type

R-Square values

Trial	IKONOS merged	IKONOS mss	LISS III PAN	ETM PAN	LISS III
With Strata	0.39	0.403	0.222	0.356	0.438
Without Strata	0.27	0.286	0.222	0.212	0.343
Pine only	0.08	0.045	0.046	0.106	0.133
Other than Pine	0.228	0.164	0.261	0.162	0.322
SQRT	0.454	0.321	0.147	0.187	0.14

Table-3 R-Square values from the regression analysis

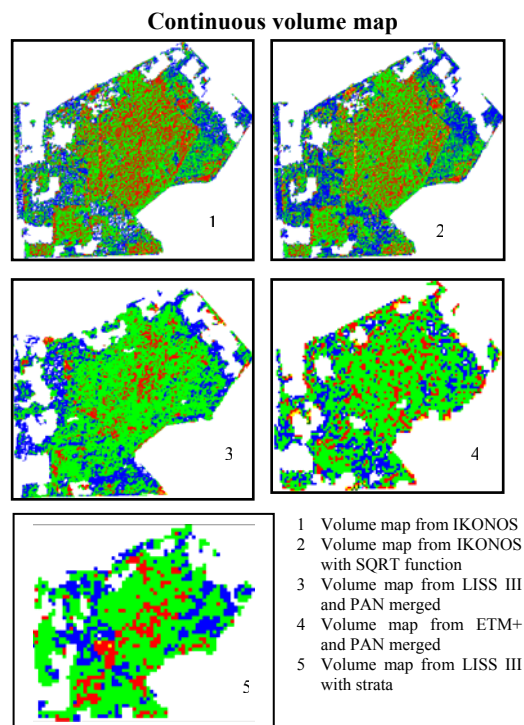


Figure 3 Continuous Volume map prepared by using different best fit equations

Discussion

The logic behind replacing the first PC with the PAN data is that the PAN data is equivalent to the first PC image. First PC contains the information, which is common to all bands, and it also accounts for maximum variance, which can maximize the effect of the high-resolution data in the fused image. (Vani *et al.*, 2001)

The operational method for this study can be suggested for the integration of remote sensing data and field assessment data for the estimation of forest parameters i.e. timber volume, tree density, biomass etc. The feature extracted from the satellite image can be correlated by means of a linear regression fit with the input of spatial information of sample plot allocation. Thus the output can estimate timber volume in the form of a continuous volume map with geographical extent, which will best compare with the real world distribution of the timber volume. However in this study the regression fit shows a rather weaker relation between field measured timber volume and pixel information, it becomes clear that the growing stock of the forest also contribute on reflectance values for satellite image to some extent and we can prepare continuous volume of the forest from remotely sensed images within the limit of precision.

By visual interpretation we can also assess the output of the study from different satellite data with different spatial resolution. Only the visual inspection can not give convincing comparison in variations of output, thus we can analyse the R-Square values of the best-fit linear equation which were used for volume map preparation and compared the percentage of area delineated under the different classes of timber volume.

Sources of errors

The reasons behind the high stand- and plot-level estimation errors are the variation in the size of pixel and plot size (Pekkarinen, 2002). The accuracy of the volume estimation in this study depends mainly on classification accuracy of the forest types and the accuracy of the estimation model for timber volume (Tiwari, 1994). McRoberts *et al.* (2002) also discussed the accuracy and errors during the use of satellite imagery for forestry application. He has noticed also the image registration error, plot location error, stratification error and volume estimation error (McRoberts *et al.*, 2002). Three sources of error were identified in this study as following:

- Spatial location of the sample plots and georeferencing:
- Estimation of volume from the sample measurement
- During the pixel information reading

6. CONCLUSION

Even though the R-Square values are below 50% in all cases of all set of data, still the analysis shows a weak relationship between timber volume and the remotely sensed pixel information. Thus the pixel information of satellite imagery can contribute to estimate the timber volume within the limit of precision shown by the R-Square value. The IKONOS PAN sharpened image and LISS III data could contribute more to the timber volume estimation, higher R-Square values i.e. 0.454 and 0.438 respectively.

R-Square values are approximately the same for IKONOS MSS data having resolution 4m and LISS III data having 23.5 m resolution with slightly weak relation. But very weak relationship has been shown in ETM+ PAN sharpened image having 15m resolution and LISS III PAN sharpened image having 5.8m resolution, as they have 0.222 and 0.212 R-Square values respectively. Thus it could not be concluded that only higher spatial resolution can contribute to the timber volume estimation. The result shows that not only spatial resolution of remotely sensed data does not effect but also the spectral characteristics can contribute for the estimation of timber volume..

Because of the distortion of pixel information during the sharpening process, PAN sharpening has a slightly negative effect on timber volume estimation as the original images have given slightly better result than PAN-sharpened images. PAN sharpening of images improves the classification of forest types with the object-oriented method of classification, which was adopted as the classification method for this study.

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