achieved, in wild types by advanced machinery available for pulverization of such material. In addition, wild-type plants are more easily available in the market due to their several fold higher productivity of roots compared to cultivated plants. At present DMAPR has a large collection of wild-type Ashwagandha and utilization of these for selecting superior chemo-types is in progress.

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Bamboo resources mapping using satellite technology

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Identification of bamboo-growing areas is important for proper planning and management of the resources. Space technology has been playing a vital role in the mapping and identification of natural resources. Not much work has been done on the estimation of bamboo-growing areas using remote sensing and geographic information system due to the mixing up of reflectance value with other forest classes. The present study explores the possibility of developing an index specific to bamboo (bamboo index) using red, NIR and SWIR bands of IRS P6 LISS-III imageries to identify the bamboo-growing areas of the NE region.

Keywords: Bamboo index, remote sensing, resources mapping, satellite technology.

MAPPING and monitoring of the spatial extent of bamboos growing in the NE region is a high-priority requirement for the planners and resources managers. The conventional method of surveying and estimating the growing stock is time-consuming and also involves high cost. However, the development in space technology, particularly the repetitive satellite remote sensing (RS) across various spatial and temporal scales, offers the most economic means of assessing, planning, managing and monitoring the forestry resources, including bamboo. The multi-faceted bamboo-based livelihood development plan can be effectively monitored using RS and Geographic Information System (GIS) techniques due to its inherent advantages and scientific knowledge-based analysis. The role of RS and GIS in the field of resources mapping has already been established as a scientific and cost/time-effective means[1]. There have been few attempts to identify bamboo-growing areas using RS and GIS techniques. One such attempt was made to prepare a map showing open bamboo brakes and forest areas for Meghalaya[2]. In the study, hybrid knowledge-based approach was attempted because unsupervised and supervised classification has limitations to be used in the regional-level classification covering large areas due to intermixing of various land-cover types, radiometry of each scene, mapping of spectrally non-discriminable objects, etc. RS and GIS have been used extensively to identify bamboo-growing areas using spectral analysis of forest-cover types and a knowledge-based classification technique for different bamboo species[3]. GPS, training set data and Normalized Differ-

ences Vegetation Index (NDVI) have been used to prepare the bamboo resources mapping of Tripura[4].

The spectral reflectance of a plant is determined by the characteristics of its leaves. The spectral reflectance of an individual leaf or needle is controlled by a number of factors, the most important being absorption by photosynthetic pigments and water. Linear Imaging Self Scanner (LISS) III of the Indian Remote Sensing (IRS) satellites sensor with 23.5 m spatial resolution enables us to discriminate different forest types, grasslands and plantations using different spectral bands. The spectral bands available in this sensor are green (0.52–0.59 µm), red (0.62–0.68 µm), NIR (0.77–0.86 µm) and SWIR (1.55–1.70 µm). Various mathematical combinations of the multi-spectral bands have been found to be sensitive indicators of the presence and conditions of specific types of green vegetation. These mathematical quantities are called as indices. In the present study, one index has been developed and applied to identify the bamboo-growing areas in the NE states.

The available literature shows that it is difficult to identify bamboo-growing areas with standard supervised and unsupervised classification techniques using raw satellite image. Therefore, an attempt to develop an index to map the bamboo-growing regions over a larger study area using RS and GIS techniques, has been made in this study.

As a part of the bamboo index development site, three wild bamboo-growing areas of the NE region (NER) – one from the plains of Tinsukia district (Upper Dihing Reserve Forest East Block) and the other two from hilly districts, NC Hills district (Langting Mupa Reserve Forest), Assam and Dampa Reserve Forest, Mizoram were selected. The index thus generated was validated in the Papum-pare district, Arunachal Pradesh (Figure 1).

IRS P6 LISS sensor type III has been used to identify the bamboo-growing areas in this study. The imagery was subjected to various preprocessing techniques (including top of atmospheric correction, radiometric correction,

etc.) in order to obtain geographically referenced data. In order to measure/estimate an area from the satellite data, it has to be initially rectified to correct the geometric errors and made planimetrically true to standard topomaps. The topomaps pertaining to the study area were referred to for ancillary information. The projection parameters used in the study were LCC with WGS84 datum.

The spectral profile of a designated pixel of different land-use/land-cover classes, including bamboo, has been studied in a few patches of known bamboo growing areas, which have been taken as the index development sites (Figure 2).

Figure 2 shows that bamboo-growing areas (magenta) can be spectrally differentiated using a combination of red, NIR and SWIR bands. An improved technique has been adopted using NDVI as a measure of vegetation health and stress index (SI) as a measure of leaf water content. These indices are defined as[5,6]

$$NDVI = \frac{NIR - RED}{NIR + RED},$$

$$SI = \frac{NIR - SWIR}{NIR + SWIR}.$$

Theoretically, delineation of bamboo areas using SI should be possible as it determines the leaf water content of plants; and leaf water content of bamboo is less compared to the other forest types. The index value difference of bamboo with other land-use classes was less. To increase this difference, a normalized (double) difference bamboo index (BI – proposed name) was prepared using NDVI and SI. The resultant imagery was used to identify bamboo areas based on the index values (Figure 3). The mathematical combination of bands used to generate BI is

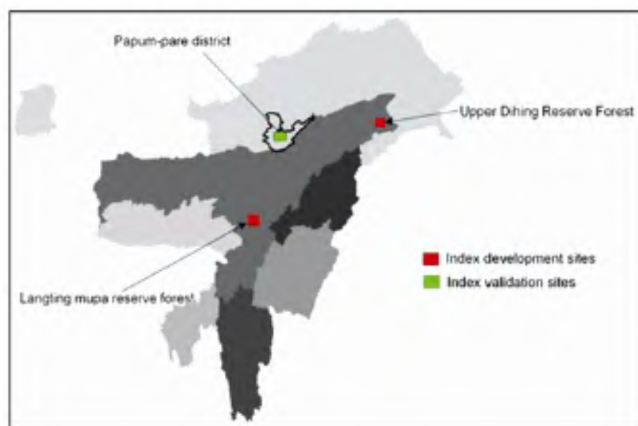$$BI = \frac{NDVI - SI}{NDVI + SI}.$$

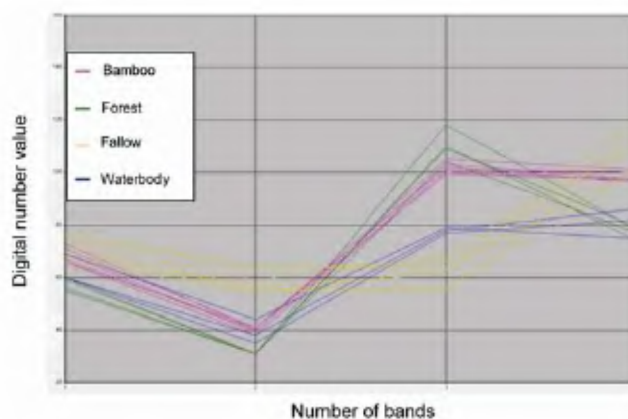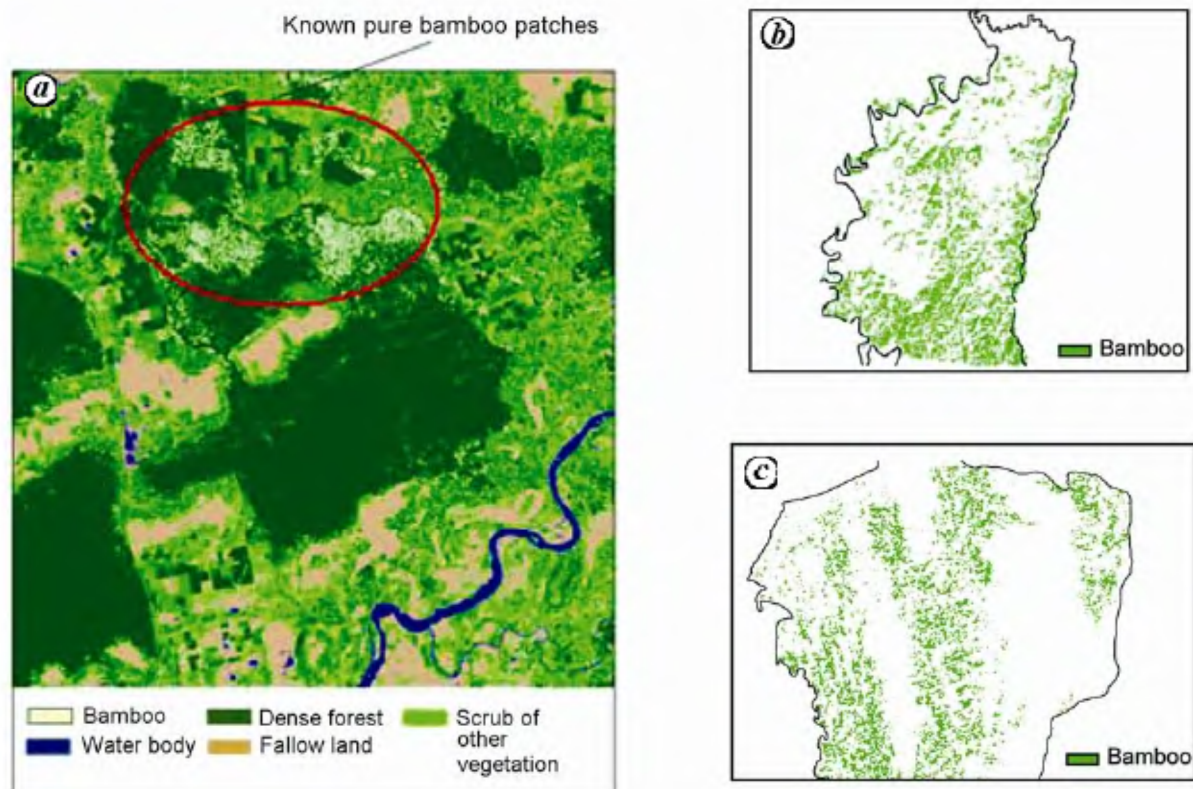

Figure 1. Study area.

Figure 2. Spectral profile of bamboo and other major land-use classes.

Figure 3. Bamboo area classification using bamboo index of East Assam Circle Forest (*a*), Lagting Mupa Reserve Forest (*b*) and Dumpa Reserve Forest (*c*).

**Figure 4.** NDVI map (*a*), SI map (*b*) and BI map (*c*) of Papum-pare district.

It has been observed that the normal bamboo BI range lies between 0.06 and 0.08 for all the study sites. The result was also verified with the existing ground-truth information available with us.

BI thus generated has been used in the Papum-pare district (Figures 4 and 5) to validate the methodology developed in other parts of the NE plain as well as hilly areas. The classified map was used in ground-truth survey and the result was found to be satisfactory.

BI was validated in the hilly terrain of Arunachal Pradesh. The overlapped area between two scenes was used to identify the index value for the bamboo class for adjacent images. It has been observed that tea gardens, fallow lands, etc. are also sometimes misclassified as bamboo areas. A combination of supervised and unsupervised classification was used for optimum results to identify few major classes such as forest area, scrub land, fallow/agriculture land, water body, snow and cloud. To minimize the error, masking of bamboo areas has been done from extracted pure forest and scrub land to eliminate the fallow land misclassified as bamboo.

As the study was undertaken to identify the bamboo-growing areas only, the statistics was also generated for bamboo areas only. Other land-cover classes were identi-
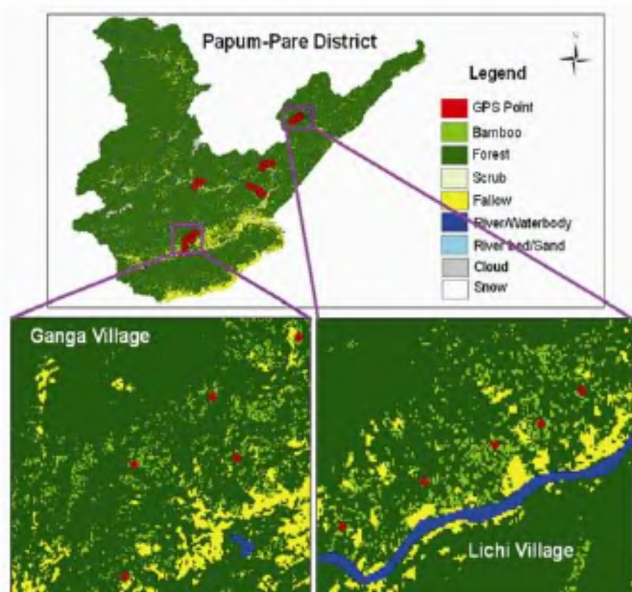
Figure 5. Mapping of bamboo-growing areas using BI in Papum-pare district.
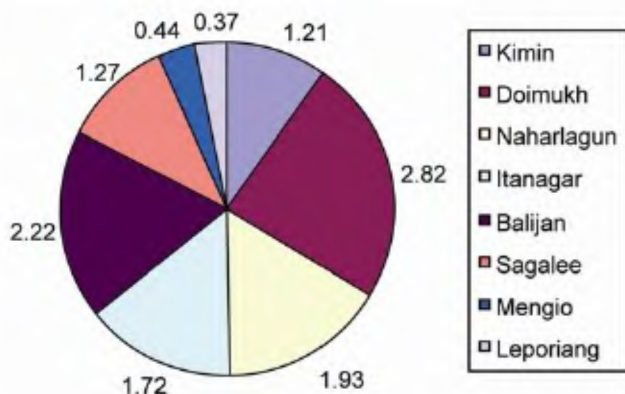
Figure 6. Distribution of bamboo-growing areas (%) in different circles of Papum-pare district.

Table 1. Circle-wise estimate of bamboo-growing areas in Papum-pare district

Circle	Geographic area (km^2)	Bamboo area (km^2)	Percentage of bamboo to circle geographic area
Kimin	549.21	6.63	1.21
Doimukh	124.72	3.52	2.82
Naharlagun	172.49	3.33	1.93
Itanagar	175.23	3.02	1.72
Balijan	749.4	16.62	2.22
Sagalee	733.07	9.34	1.27
Mengio	580.44	2.57	0.44
Leporiang	307.33	1.13	0.37
Total	3391.89	46.16	

fied to avoid misclassification and reduce the error. The study is well supported by adequate ground truth. Accuracy assessment was done and it was found that the overall classification accuracy among four classes (i.e. forest, bamboo, fallow and water bodies) was 84% with a kappa value of 0.79. Total bamboo-growing area in the Papum-pare district was estimated as 46.16 km^2, whereas the total geographic area of the district was 3391.89 km^2. Individual circle-wise estimates of bamboo-growing areas are given in Table 1. Graphical representation of the percentage of bamboo areas in each circle is given in Figure 6. The actual geographic area of individual circles has been calculated based on circle boundary readily available with us. Therefore, there may be little mismatch of total geographic area from the notified records.

The present methodology will be useful to map and monitor the bamboo-growing areas more efficiently and in a cost-effective manner.

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