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Monitoring of bamboo flowering using satellite remote sensing and GIS techniques in Mizoram, India

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Abstract

Mizoram is endowed with bountiful natural resources, of which bamboo is the prominent and most abundant of the forest resources. With about 32% of the total geographical area of the state occupied by bamboo, this valuable and important resource has a peculiar lifecycle where it flowers and dies after every 48 years. Such being the case, bamboo flowering has a huge impact not only on the vegetative composition but also the socio-economic condition of the state. The spatial distribution and progression of the bamboo flowering in Mizoram was monitored and studied for a period of 5 years (2005 to 2009) using satellite remote sensing and geographic information system (GIS) techniques, involving applications of vegetative index models. The cumulative progression in flowering pattern shows successive increase in flowering areas which recorded a maximum of 73.83% out of the total bamboo forest, at the end of the study period. The present study also gives a comparative analysis of the district-wise spatial distribution of bamboo flowering that may serve as a useful data for preparation of schemes to mitigate the impacts of bamboo flowering in future.

Key words: Bamboo flowering; satellite remote sensing; GIS; vegetative index models.

Introduction

Bamboos are tall, perennial, arborescent grasses, belonging to the family Poaceae (Graminae). They form a major vegetative component of forests in Mizoram and have a specific lifespan which is unique for each species. In India, north eastern region has a great diversity and culture of bamboo. India has the world's richest resources of bamboo occurring over an area of 10.05 million hectares or about 12.8% of the total forest area of the country.[1] Bamboo flowering marks the end of the lifespan which is usually gregarious. In Mizoram, gregarious flowering occurs after a period of 48 years in *Melocanna baccifera* and *Bambusa tulda* [2] and in *B. arundinaceae*.[3] This peculiar behavior of bamboos has intrigued mankind for long and still remains a mystery.[4]

Although no detailed scientific study is available, there are reports that document the historical occurrence of bamboo flowering and resulting in famine in north-east India, particularly

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Mizoram. The recorded bamboo flowering in Mizoram suggests that the two earlier events of gregarious flowering occurred in 1911-1912 and 1959-1960 respectively. The last gregarious flowering of *muli* bamboo (*M. baccifera*) in Mizoram was reported in 1958-59 and was followed by famine. In some places, flowering of *Dendrocalamus hamiltonii* had also been observed. The gregarious bamboo flowering and death, followed by famine is called 'Mautam' by the people of Mizoram. Prior to gregarious flowering of *M. baccifera*, records have shown the flowering of another species of bamboo, i.e. *B. tulda* in 1881, 1929 and 1977 which are flowering-precursors of the *M. baccifera* species. This flowering of *B. tulda* is called 'Thingtam' by the Mizos.

The phenomenon of gregarious bamboo flowering in Mizoram is followed invariably by an increase of local rat population and has been known to cause famine as the rodents also feed on cultivated crops causing extensive damage to food supply. The phenomenon also triggered a plague of bugs called Thangnang in Mizo (scientific name *Ochrophara montana* or *Udonga montana*). These bugs swarm in millions during mass flowering of *M. baccifera*. They are also known to eat the seeds of *Dendrocalamus strictus* and *Bambusa* spp.

Bamboo forest of Mizoram mainly constitute of *M. baccifera*, as it is the dominant bamboo species in the state, covering 95% of bamboo forest.[3] These bamboo forests are abundant in the state except in the eastern parts, particularly in Champhai District. Mapping of bamboo forest using remote sensing and GIS technique is the prior requirement for identifying their distribution and monitoring the pattern of flowering. Satellite imagery with embedded spectral values provides a wide range of spectrum for extraction specific vegetative information. Since long, satellite remote sensing has been used to map and classify land use and forest cover. The technology has made it possible to prepare maps of remote, inaccessible and mountainous regions.[5] Discrimination of vegetation cover might be sometimes difficult among species having similar spectral reflectance, however, phenological variability and multi-date satellite data have been found very useful in characterising vegetation through various enhancement methods and classification algorithms.[6] To achieve higher accuracy in vegetation mapping, other methods of classification such as hybrid approach where modification of spectral classification, aided with ancillary data [7] and use of vegetation index models has been found useful. The present monitoring of bamboo flowering also utilizes these capabilities of satellite remote sensing and GIS technology to characterize and map the important phenological stage of bamboo, i.e. flowering area. In addition, the other objectives of this study involve cumulative comparison of bamboo flowering areas.

Materials and Methods

Study area

The study area covers the entire state of Mizoram, located in the northeastern India. It is characterized by hills with sparse to dense forest throughout. The state has a geographical area of 21,081 sq km and lies between the coordinates of 21° 58' and 24° 35' N Latitude, and 92° 15' and 93° 20' E Longitude (Fig. 1), with the tropic of cancer passing through the state at 23° 30' N latitude.

The state has a climate ranging from moist tropical to moist sub-tropical. During winter, the temperature varies from 9.4 to 25.5°C and in summer, it varies between 14 to 33.1°C.[14] The state is under the direct influence of southwest monsoon, with an average annual rainfall of 2693.4 mm.[14]

The physiography of Mizoram can be broadly divided into hills and valleys. The physical set-up is composed predominantly of mountainous terrain of tertiary rocks. The hilly terrains (high hills) are undulating with average altitude above 1300 m (msl), medium hills with altitudes ranging between 500 and 1300 m and low hills with altitudes below 500 m above msl with the maximum reaching 2,157 m in Phawngpui (Blue Mountain).[9]

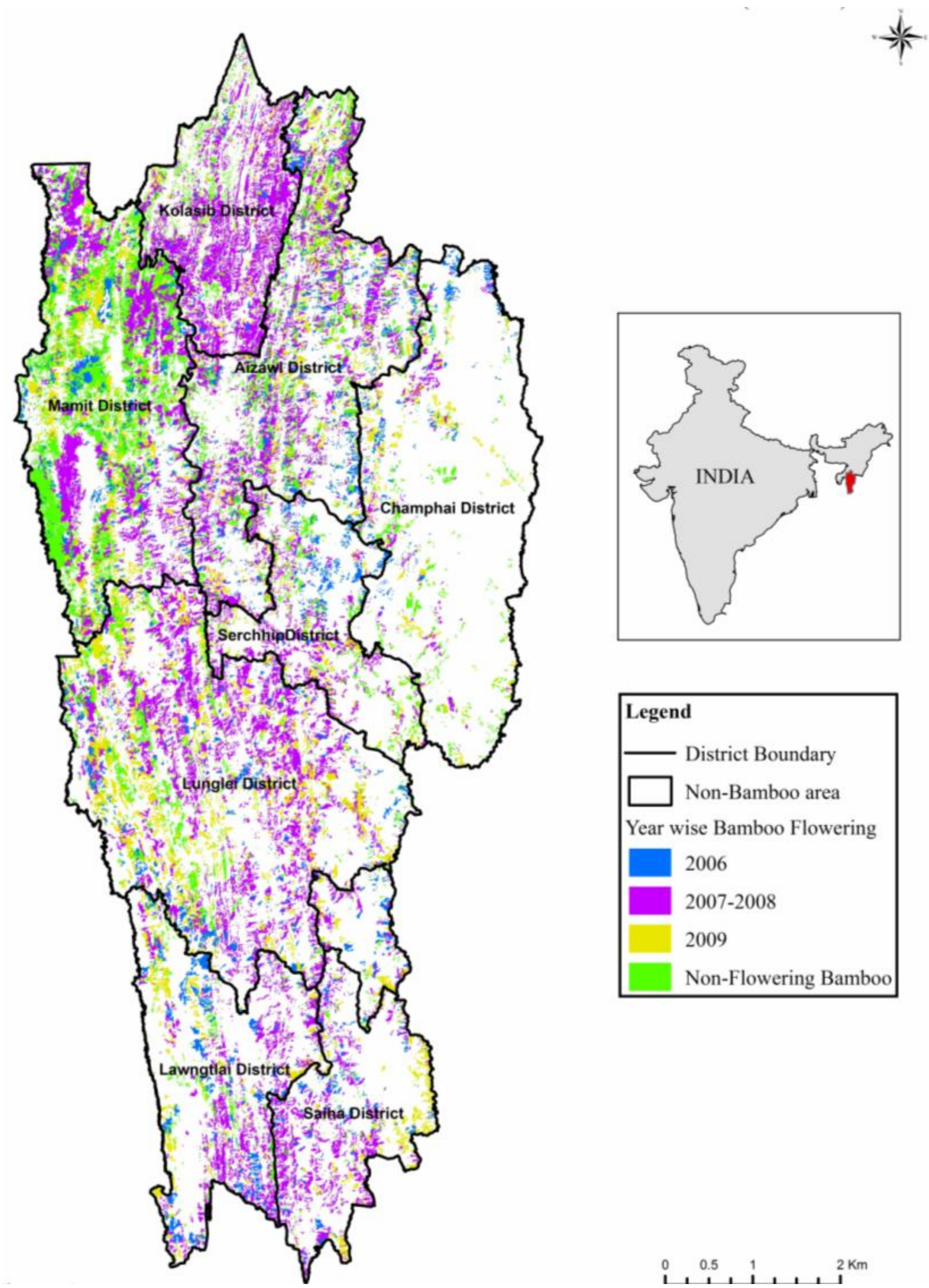

Figure 1. Map of bamboo forest and flowering areas in Mizoram (2005-2009).

On the basis of Champion and Seth classification system (1968), the forests of Mizoram have been broadly divided into four forest type groups, *viz.* Tropical semi-evergreen forest, Tropical moist deciduous forest, Sub-tropical broad-leaved hill forest and Sub-tropical pine forest.[8] Bamboo forest constitutes a majority of understory species of Tropical moist deciduous forest type. [16]

Data used

Satellite imagery (LISS III) of IRS-P6 for multiple years (2005-2009) was acquired from National Remote Sensing Centre (NRSC), Hyderabad. Other ancillary data like Survey of India Toposheets, existing land use/ land cover, roads, settlements, etc were also used for preparation of base layer. Reports of past inventory on bamboo resources from Environment and Forest Department, Forest Survey of India, etc. were also referred to. Ground data collected for verification of doubtful areas arising during the pre-classification stage were used for correction of interpreted layers.

Data processing and mapping

The mapping and analysis of bamboo flowering areas in Mizoram was carried out utilizing satellite remote sensing and GIS technique. ERDAS Imagine (digital image processing software) and Arc Info were used for data processing, storage, analysis, generating results and producing maps on 1:50,000 scale. Spatial and non-spatial data from other ancillary data sources were combined to generate the maps. Standard procedures of this technique combined with ground data and other relevant information were used to assess and estimate the area of bamboo during its gregarious flowering.

All satellite data (IRS P6 - LISS III) were geo -coded and geo-referencing by extracting Ground Control Points (GCPs) from previously referenced imagery and SOI Toposheets. Digital image enhancement and application of correction models for making the digital data free from error and distortions in terms of radiometry and geometry of the satellite data was also done. Customized image processing models were also used during the initial stages of digital classification to extract bamboo forests. Various mathematical combinations of the spectral signatures from IRS P-6 LISS III have been found to be sensitive indicators of the presence and conditions of green vegetation, referred to as vegetation indices. The spectral bands are thus used for formulating the vegetative index models.

Normalized difference vegetation index (NDVI) is normally calculated as:[10] NDVI = (NIR – Red) / (NIR + Red), where NIR is the spectral radiance in the near infrared region (LISS III - Band 3) and Red is the spectral radiance in the visible red region (LISS III - Band 2). The NDVI equation theoretically produces values in the range of –1.0 to 1.0,[11] where the positive values indicate increasing green vegetation and negative values indicate non vegetated surface. The values can differ with the type of data used, e.g. in highly vegetated scene of AVHRR data, it ranges from 0.1 to 0.6, in proportion to the density and greenness of the plant canopy.[12] The stress index (SI) model adopted in this study was used to evaluate the water stress condition in bamboo, as they are known to be under such influence during their stages of fruiting and flowering. SWIR (short wave infra-red) band, available in IRS P6 LISS III, is more sensitive to water content than NIR or red bands. To assess water content in a normalised way, the NDWI (normalised difference water index) introduced by Gao in 1996[13] was used. The NDWI (SI) using SWIR and NIR is suitable for evaluating vegetation water status and calculated as: NDWI (SI) = (NIR-SWIR)/(NIR+SWIR); where NIR is band 3 (0.78-0.89 µm), and SWIR is band 4 (1.58-1.75 µm) of LISS III. The combination of these two indices (NDVI & SI) yields a strong positive correlation and useful for evaluating the vegetation canopy status. It was suggested to derive a new Index model to arrive at a model that would enable the extraction of bamboo forest. Thus the integration of the two vegetation indices i.e. NDVI and SI yielded a new

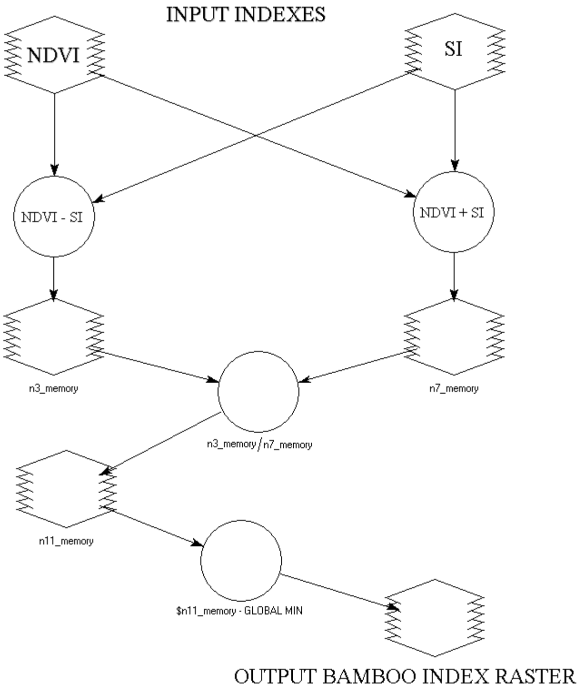

Figure 2. Bamboo Index Model.

type of vegetative index model known as the Bamboo Index Model, calculated as:

BI (Bamboo Index) = NDVI – SI / NDVI + SI (Fig 2).

The final raster layer derived as a result of combination of the indexes was then re-checked and misclassified bamboo areas were re-coded again into the bamboo class. This layer was then converted into vector format for further visual interpretation/extraction of bamboo flowering areas for the subsequent years. Post interpretation data collected during ground truthing of doubtful areas was also incorporated in the final stages of GIS analysis using ARC-INFO GIS software. Standard methodology required for generating cartographic outputs eg: creation of topology, spatial data corrections, etc. was then carried out to represent the GIS output in the form of bamboo cover map showing the distribution of the bamboo flowering areas.

Results and Discussion

The bamboo layer of 2005 was used as the base layer for deriving flowering areas in the subsequent years. Mapping for the following years till 2009 was done to monitor the cumulative flowering areas that give a conceptual pattern of the gregarious flowering phenomenon of bamboo as discussed below.

Bamboo forest area in 2005

The total area of bamboo based on 2005 mapping is 6840 sq km or 32.45% of the total geographic area of the state. This is almost similar with the area obtained in the other studies by MIRSAC, *viz*. 33.63% in Mapping and Growing Stock Assessment of Bamboo in Mizoram[16] and 31.81% in Natural Resources Atlas of Mizoram.[17] Slight difference in the bamboo area may be due to the differences in the year of data, satellite resolution, methodology of mapping, etc. In addition, there is a dynamic change in bamboo forest every year due to shifting cultivation. It is observed that *M. baccifera* is occurring mostly between the altitudinal range of 80-1400 m MSL. The distribution of bamboo forest in various altitudinal zones are 60.16% in 0-500 m, 36.34% in 500-1000 m and 3.48% in 1000-2000 m above msl.

The area-wise and percentage distribution of bamboo in different districts of Mizoram for the year 2005 is shown in Table 1. Mamit district

Table 1. Bamboo area in Mizoram during 2005.

Districts	District area (Sq Km)	Bamboo area (Sq km)	Bamboo area (%)
Kolasib	1382.00	692.62	50.12
Mamit	3025.00	1737.05	57.42
Aizawl	3576.00	1214.52	33.96
Champhai	3185.00	308.31	9.68
Serchhip	1421.00	372.17	26.19
Lunglei	4536.00	1545.03	34.06
Lawngtlai	2557.00	613.54	23.99
Saiha	1399.00	356.75	25.50
Total	**21081.00**	**6840.00**	**32.45**

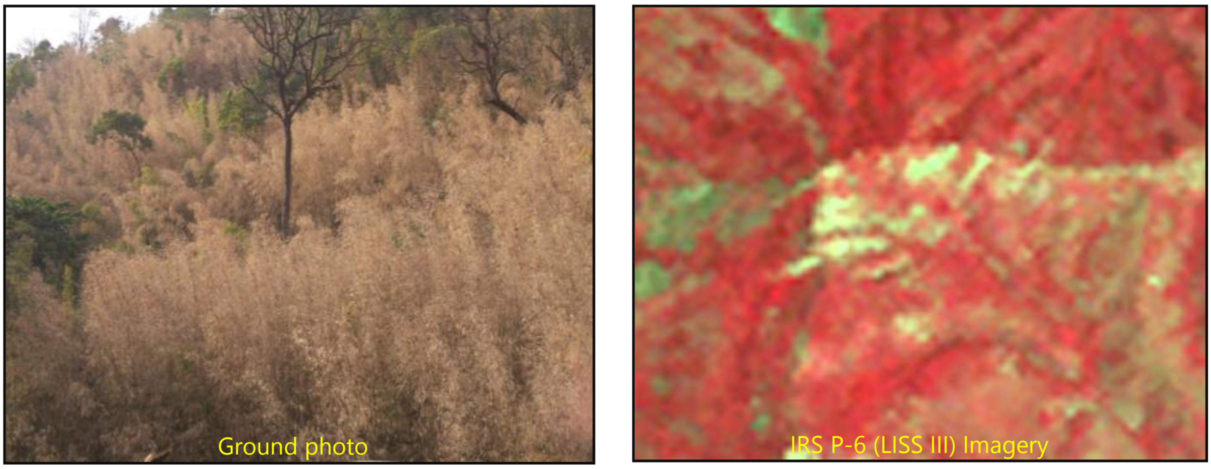

Figure 3. Ground photo of bamboo flowering in Saiha district and its location on IRS P-6 (LISS III) satellite imagery.

has the highest bamboo area of 1737.05 sq km out of the total bamboo area of the state which is 6840 sq km. Champhai district recorded the lowest bamboo area of 308.31 sq km, followed closely by Saiha district with an area of 356.75 sq km. This trend also holds true for bamboo coverage within each of the districts, with Mamit district recording a highest bamboo cover of 57.42% of its district area followed by Kolasib district with 50.12% coverage. Champhai district recorded a minimum bamboo area of 9.68% of its total district area.

Bamboo flowering in 2006

The analysis of bamboo area for the year 2006 presents a different picture as the bamboos mapped during this year had started flowering. The 2005 bamboo layer overlaid on the 2006 satellite data showed considerable change in bamboo forest cover. Considering the scenario of the whole state, not much of the bamboo had flowered in 2006 and the bamboo flowering area constituted only 783.03 sq km, i.e. 11.45% of the total bamboo area. Comparative analysis of 2006 data shows that maximum bamboo flowering occurred in Aizawl district with an area of 164.06 sq km covered by bamboo flowering out of the total bamboo area of 1214.52 sq km (Table 2). This accounted for 13.51% of total bamboo area in the district. However, the highest percentage of bamboo flowering is found in Lawngtlai district with 22.03%. In general, it can be said that the area of bamboo flowering (percentage-wise) during 2006 is comparatively higher in Lawngtlai, Champhai, Serchhip, Saiha and Aizawl districts.

Table 2. Bamboo flowering statistics in 2006.

Districts	Bamboo area (Sq Km)	Bamboo flowering area 2006 (Sq km)	Bamboo flowering area (%)
Kolasib	692.62	20.38	2.94
Mamit	1737.05	149.30	8.59
Aizawl	1214.52	164.06	13.51
Champhai	308.31	57.74	18.73
Serchhip	372.17	62.47	16.79
Lunglei	1545.03	147.02	9.52
Lawngtlai	613.54	135.14	22.03
Saiha	356.75	46.92	13.15
Total	**6840.00**	**783.03**	**11.45**

Bamboo flowering in 2007 and 2008

Since no cloud-free satellite data is available for the year 2007, the data of 2008 were utilized to study the bamboo flowering area during 2007 and 2008. The 2008 data has shown tremendous increase in bamboo flowering owing to the gregarious flowering periods during 2007 and 2008. This can be attributed to the peak flowering period in 2007. Within a span of 2 years (2007-2008), 3045.13 sq km i.e. 44.51% of the total bamboo area flowered. The cumulative area of bamboo flowering for three years (2006-2008) is 3823.16 sq km, i.e. 55.97% of the total bamboo forest area. Considering the cumulative flowering area of bamboo forest, Lunglei district contributed the highest bamboo flowering of 879.20 sq km (56.91% of total bamboo area in the district) compared to other districts. Percentage-wise, when compared with the total bamboo cover in each district, Kolasib and Saiha districts recorded a high of 78.86% and 73.29% respectively (Table 3). This indicates that almost entire bamboo area in the districts had started to flower. Except for Mamit and Champhai whose percentage of bamboo flowering is below 50%, it can be inferred that in all the other districts more than half of the total bamboo areas have flowered.

Table 3. Bamboo flowering statistics in 2007-2008.

Districts	New bamboo flowering area 2007-2008 (Sq km)	Bamboo flowering area 2006-2008 (Sq km)	Cumulative bamboo flowering area (%)
Kolasib	525.85	546.23	78.86
Mamit	529.19	678.49	39.06
Aizawl	534.07	698.13	57.48
Champhai	65.83	123.58	40.08
Serchhip	164.32	226.78	60.94
Lunglei	732.18	879.20	56.91
Lawngtlai	279.14	414.27	67.52
Saiha	214.55	261.48	73.29
Total	**3045.13**	**3828.16**	**55.97**

Bamboo flowering in 2009

Since the peak period of flowering is already over, the new flowering areas are found in a sporadic pattern. It is observed that most of the bamboo had flowered at this stage. An increase of bamboo flowering area of 1221.90 sq km, i.e. 17.86% of the total bamboo forest area was observed in 2009. The cumulative area of bamboo flowering is 5050.06 sq km, i.e. 73.83% of total bamboo forest. Significantly large percentage of flowering areas were found in Saiha, Lawngtlai, Lunglei and Kolasib districts, with Saiha district recording the highest percentage of cumulative bamboo flowering in 2009 (Table 4). Area-wise, Lunglei district contributed the largest area of bamboo flowering compared to all other districts in the state.

The initial flowering year (2006) of the study period shows that bamboo flowering was prominent in Champhai, Serchhip and Lawngtlai districts. The cumulative trend was however, superseded by districts to the southern and northern part of the state – Saiha, Lunglei, Lawngtlai and Kolasib. The graphical representation (Fig. 4) shows a cumulative depression in the central part of the state, indicating bamboo flowering was more prominent towards the north and southern areas of Mizoram during the later course of the study period.

Findings from this study indicate that the flowering of bamboo resulted in a loss of 73.83% of bamboo forest till 2009, out of the total bamboo forest area of 6840 sq km. Previous studies on the loss of bamboo culms indicate that an estimated total of 3324.63 million culms (66.77%) were lost due to bamboo flowering during 2006-2008.[16] However, it was observed that regeneration starts in the under-storey at various places. It may be noted that 26.17% of the bamboo areas had not flowered in the year 2009. The non-flowering areas appear to be dominated by other species of bamboo (*Dendrocalamus* spp., *Bambusa* spp.). This case can be observed in areas to the western part of the state like Mamit district where non-flowering areas were still prominent at the end

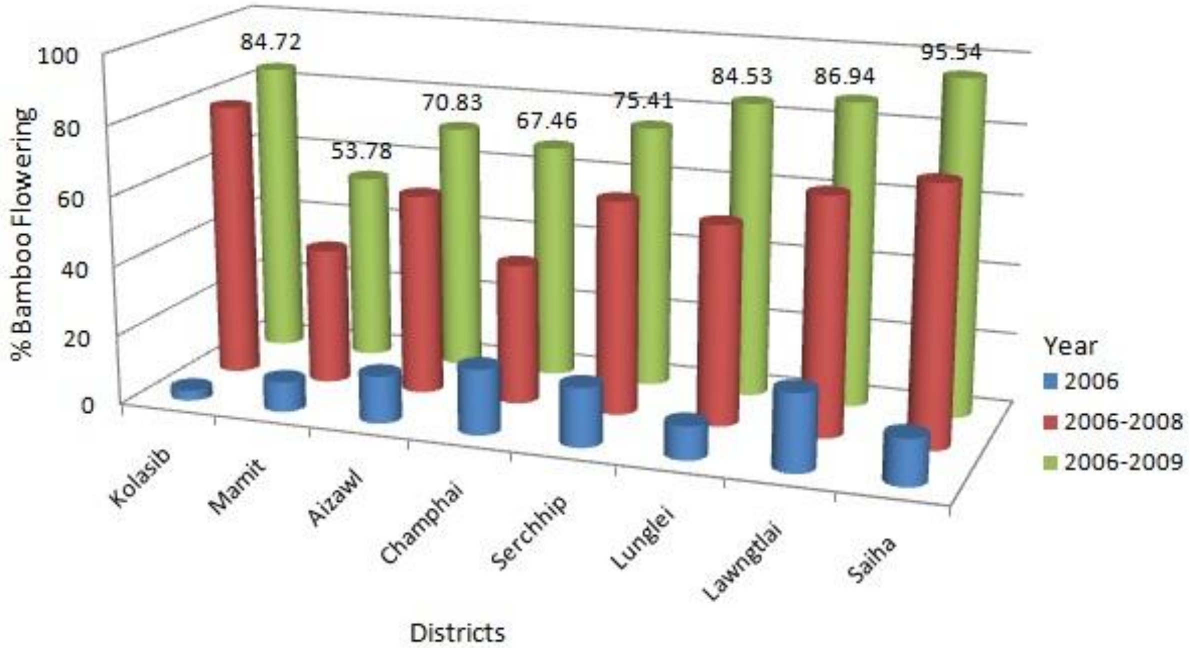

Figure 4. District-wise cumulative bamboo flowering (2006-2009).

of the study period. It has also been recorded that there are bamboo reserve areas owned by village communities from which extraction of bamboo is restricted only for basic domestic needs. It was also observed that there are some patches of bamboo forest (*M. baccifera*) which do not flower and are 'left-over' during the gregarious flowering period. This can be tracked in the flowering history of *M. baccifera* in Mizoram.[15]

Table 3. Bamboo flowering statistics in 2007-2008.

Districts	New bamboo flowering area 2009 (Sq km)	Bamboo flowering area 2006-2009 (Sq km)	Cumulative bamboo flowering area (%)
Kolasib	40.58	586.81	84.72
Mamit	255.65	934.14	53.78
Aizawl	162.05	860.19	70.83
Champhai	84.42	207.99	67.46
Serchhip	53.87	280.65	75.41
Lunglei	426.83	1306.03	84.53
Lawngtlai	119.14	533.41	86.94
Saiha	79.36	340.84	95.54
Total	**1221.90**	**5050.06**	**73.83**

Larger percentage of the bamboo flowering areas has been contributed by the gregarious flowering of *M. baccifera* which is the most abundant bamboo species in Mizoram. There have been incidences of sporadic flowering of other species of bamboo, e.g. *Dendrocalamus* spp. during the course of this study, yet their contribution to overall flowering area is meager.

Conclusion

In the present study, multi-date satellite data of IRS P-6 were utilized for mapping and monitoring the phenomenon of bamboo flowering. It gives the area and synoptic view of flowering pattern for a period of 5 years and also the specific location and distribution pattern of *M. baccifera*. The phenomenon of gregarious bamboo flowering is a matter of state as well as national concern, for which the central and state government has implemented various combat schemes to minimize its disastrous effect on rural economy. The effectiveness of these combat schemes can be improved by using database available for the flowering areas. The database created from this study will also be useful in the next cycle of flowering as the current data can provide a scenario of its coverage and it would also help in forecasting the impacts of bamboo flowering in the next cycle. It is also envisaged that such information derived can be used as vital inputs for further analysis, experimentation and forecasting/modeling of future incidences of bamboo flowering.

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