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Estimation of phenological parameters using remote sensing derived high temporal LAI data: A case study of forest region in central India

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Abstract: Deciduous forests show distinct phenological changes during different seasons. In the present study, phenological changes of some plant communities have been tracked using remotely sensed Leaf Area Index (LAI) from MODISfor the forested watersheds located near Kanha National Park of Madhya Pradesh State. LAI profiles were modeled using polynomial functions. Field data were collected for each forest type in terms of location, extent and phenophases. Different phenological parameters like duration of leaf flush period, leaf less period, period of halfway change during leaf fall and leaf flush, leaf flush rate, leaf fall rate, leaf strategy index were derived using the profiles. Considerable difference was found in the duration and amplitude of change in LAI for different communities. Sal (Shorea robusta) forest showed longer leaf flush periods and rapid leaf gain prior to onset of monsoon whereas purely deciduous species like Lendia (Lagerstroemia parviflora**)** showed longer leafless periods and early leaf shedding. Annual leaf strategy index is higher in Lendia, Sal and Bamboo (Dendrolcalamusstrictus) forest and lower values in Jamun (Syzygiumcumini). A good match between the MODIS LAI and in situ LAI (R^2= 0.87) was obtained. Study highlights the applicability of high temporal data for the phenological analysis.

Keywords: Phenology, Leaf Area Index (LAI), Polynomial functions, NDVI, Forest types

1. Introduction

Different forests types in India have developed characteristic phenological cycles as response to typical monsoonal climate (Bhatt, 1992; Boojh and Ramakrishnan, 1982; Prasad and Hegde, 1986; Kushwaha and Singh, 2005). Especially deciduous forests in central India have attracted considerable research interest due to their peculiar phenology (Singh and Singh, 1988; Singh and Kushwaha, 2005; Sagar and Singh, 2003). Precise monitoring of phenological stages is of immense importance to understand the interrelation between climatic variables like soil moisture, humidity, rainfall and vegetation (Singh and Kushwaha, 2005; Borchert et al., 2002). Trees have evolved different strategies to sustain longer dry conditions and developed into different functional communities (Borchert et al., 2002; Lavorel et al., 1997). Trees in central Indian forestsare semi-deciduous, deciduous and evergreen depending on their functional mechanisms. The phenological cycles followed by different species and same species in different environmental conditions are important to understand the nature of vegetation response of future global climate change (Gitay and Noble, 1997; Box, 1996). Remote sensing technologies have made it possible to monitor the changes in biophysical parameters such as Leaf Area Index (LAI) and Fraction of Photosynthetic active radiation (FPAR) through spectral indices such as Normalized difference vegetation index (NDVI), Reduced simple ratio (RSR), Simple ratio (SR) (Lillesand and Kiefer, 2000; Zheng and Moskal, 2009). LAI is an important biophysical parameter for understanding the different natural processes associated with vegetated land surface. Temporal profiling of LAI can directly depict the different phenophases of vegetation. Careful monitoring of vegetation through LAI study can reveal the changing patterns of vegetation composition, health status of forest, impact of prolonged drought conditions (Cowling and Field, 2003; Maass et al., 1995). LAI has been estimated from remote sensing data through empirically as well as physically based relationship between LAI and other biophysical indices like NDVI, RSR, SR (Myneni et al., 1999). The major advancement is due to availability of MODIS LAI/FPAR data products. The MODIS-LAI retrieval algorithm utilizes atmospherically corrected spectral reflectance data of MODIS sensor and also biome classification information. It uses rigorous three-dimensional radiative transfer model and look up table (LUT) approach. It compares reflectance with those determined from a suite of canopy models, which depends on biome types, canopy structure, and soil reflectance (Myneni et al., 1999; Yang et al., 2006; Tian et al., 2000). The LAI data have been proven to be useful for phenological research (Ahl et al., 2006; Fensholt et al., 2004; Zhang et al., 2006). In this study, based on the major tree species some plant communities were identified during ground survey. Their LAI profiles were extracted. LAI profiles were approximated by fitting polynomial models between date and monthly max LAI values. These models were used to interpret some of the important phenological changes such as maximum leaf flush duration, leaf less periods, rate of changes in LAI, duration of 50% changes during senescence and leaf flush from respective initial conditions in terms of LAI. The emphasis of the study was to distinguish plant communities based on their response to changing seasonal conditions and it was achieved through LAI. The differences among the major communities were then utilized to develop some logical expressions to produce map in which plant communities were delineated throughout study area.

2. Study area

The study area (Fig. 1) comprises of watershed located towards south eastern border of M.P. It covers part of Kanha national park. The spatial extent is $22^{0}02^{'}$ to $22^{0}36^{'}$N and $80^{0}24^{'}$ to $81^{0}01^{'}$ E. The total area covered is 1783 km^{2}. The area is predominantly covered with broadleaf deciduous forest. The major specie is Shorea robusta C.F. Gaertn (Sal). Other species include Syzygiumcumini (L.) Skeels (Jamun), Ougeiniadalbergioides Benth. (Tinsa), Dendrolcalamusstrictus Roxb. (bamboo), Lagerstroemia parviflora Roxb. (Lendia). Species like Diospyrosmelanoxylon Roxb. (Tendu), BoswelliaserrataTrianaandPlanch., Madhucalongifolia J.F. Macbr. (Moha) are also found. The study area has distinct monsoonal climate. In summer temperature ranges from 11 - 43^{0}C whereas in winter it varies from 02 – 29^{0}C. The mean annual rainfall is 1225 mm.

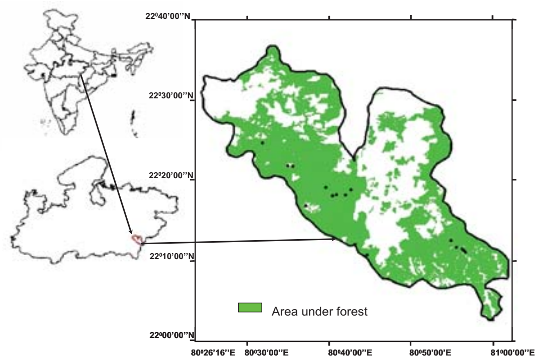

Figure 1: Watershed area showing forest area and ground truth sites

3. Data used

The 8-day composite MODIS LAI product (MYD15A2) with 1 km spatial resolution was obtained from wist.echo.nasa.gov site. There are 46 composites in a year. Study area lies in 25v06 tile. The product is available in HDF-EOS data format. LAI data for year 2009 was used for the study. They were reprojected to geographic system. The valid range for LAI in the product is 0 to 100 with 0.1 scale factor, which means that a digital number of 37 in LAI product corresponds to estimated LAI of 3.7 on ground. Land cover map derived from LISS III data at 1:50000 scale was used to obtain forest area. The map was obtained from Nature Resource Census Project. MODIS 500m daily spectral reflectance product (MYD09GA), having red (630-690nm) and near infrared (780 – 900nm) bands, were used to derive NDVI maps which were used for deriving NDVI-LAI relationship.

4. Methodology

4.1 LAI profile generation and statistical analysis

The ground truth (GT) sites were marked using the GPS (global positioning system) receiver recorded coordinates. These sites included Sal mixed forest, Pure Sal forest and forest patches dominated by Lendia, Jamun, Bamboo, Tinsa and mixed forest.LAI annual profiles were derived for all these GT sites. August dates were ignored in analysis due to cloudy conditions. Maximum LAI value of a month was extracted. Best fit polynomial transformation models were used to depict the pattern of changing LAI with time. These fitted models were then used to estimate LAI for a given day. The first and second derivatives were calculated to find out local minima and maxima of LAI with corresponding dates. The time period for which the maximum or minimum greenness prevails was obtained by considering the period for 0.1standard deviation (sd) difference from minimum and maximum LAI. These periods represent leaf less and maximum leaf flush conditions respectively. Total range through which LAI varies was derived by subtracting minimum LAI from maximum. Half of this LAI range was considered as mean LAI, which was added in the minimum LAI to get the fifty percent increase in the LAI during leaf gain period. On the other hand fifty percent fall in the LAI during senescence phase was calculated by subtraction of half of LAI range from maximum LAI. Time period covering exact 50% gain and loss were estimated considering ± 0.1sd difference. The period from minimum LAI to maximum LAI was considered to be leaf flush period. It represents increasing LAI due to production of new leaves. The period from Maximum LAI to minimum is leaf fall period. Methodology is explained in Fig. 2.

4.2 Discrimination analysis between different forest types

Two different approaches were undertaken to distinguish between forest communities. In the first approach, LAI change rate during leaf flush and leaf fall per fifteen days were calculated. These rates were then compared through leaf strategy index (LSI). LSI was first proposed by Kushwaha and Singh (2005). LSI is the ratio of leaf flush rate and leaf fall rate which represents variation in seasonal duration of deciduousness. In this study LSI was calculated as the ratio of average LAI change per fifteen days during leaf flush and leaf fall. Periods of leaf flush and leaf growth of the communities were also compared in pair through simple ratio. Second approach of comparison between different communities was undertaken keeping the fixed time scale. Two communities were compared at a time using unpaired t-test. The daily calculated values of LAI in every month from January to December 2009 were used.

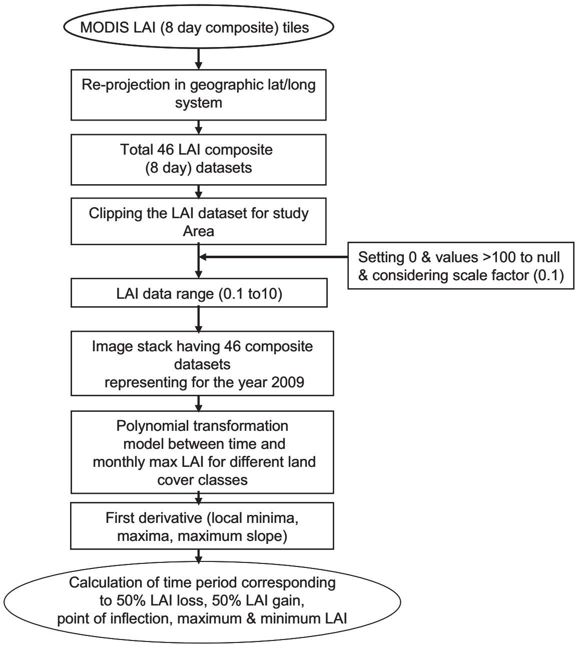

Figure 2: Flow chart for LAI profiling and analysis

4.3 Underestimation in the MODIS LAI product

In the watershed, towards the eastern and north-east parts, the LAI were found very low (mean less than 1.5) throughout the year except during the month of September (mean reaches 2.4) in densely forested pixels. Though the quality tags assigned to them showed that the data is usable, there appears to be some error in retrieval of LAI in this area whichresults in underestimated LAI. Correction was required in these parts for the mapping of forest types. The pixels, having such a lower value of LAI, were identified. Area covered by these pixels, which required corrections, was about 460 km^2.

4.4 Development of NDVI–LAI relationship

MODIS LAI product for the underestimated area, within the watershed, was rectified by developing a relationship between NDVI and LAI. This kind of site specific and empirical approach for derivation of LAI from NDVI is well established method (Lu et al., 2005; Hall et al., 1995; Boegh et al., 2004). NDVI maps were generated using MODIS surface reflectance data in Equation 1. 8-day composite NDVI maps were generated using max function (Rouse et al., 1974).

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \qquad \ldots(1)$$

This exercise was done for dates (LAI product dates) from January, March and September to have representation of complete LAI and NDVI range. Total 92 data values were considered of LAI and NDVI data sets for above mentioned dates. A scatter plot was prepared between NDVI and LAI values for 92 randomly distributed points under forest mask (where LAI estimations were proper) including GT sites, to develop an empirical relationship between them. An exponential relationship was obtained between NDVI and LAI. MODIS LAI in underestimated areas were then improvised by applying the NDVI – LAI relationship and used for further analysis.

4.5 Comparison of MODIS LAI with in situ measurements

During ground visits using leaf canopy analyzer LAI values were measured at the ground truth locations. Most of the readings were taken on 9th&10th March 2010. In July and October 2009 only two locations were covered in Sal forest (18th July and 8th October, respectively). At every location, three readings were taken and then average was calculated. Scatter plot was plotted between MODIS LAI and in situ readings.

4.6 Mapping of the different forest communities using LAI profiles

The LAI profiles for major communities obtained were studied and the period of year when they show distinct difference between LAI amplitude was obtained. Such difference was observed that during early to mid-January and mid-September. Using the dates from these two periods logical expressions were developed so as areas with different types could be spatially isolated from each other. Typical profile for Sal mixed forest LAI had LAI greater than 4 during early January and it reduced to 3.5 till early February. In mid-September it was greater than 4.5. Tinsa mix forest had higher LAI in January similar to Sal mix but it was less than 3.5 till February mid. Pure Sal forest had LAI between 2.8 to 4 during early January and more than 4.5 in mid-September. Bamboo mix forest showed LAI between 2.5 to 2.8 in early January and greater than 5.5 in mid-September. In Jamun mix forest it was between 1.7 and 2 during early January and between 4.5 and 6 till mid-September. In Lendia mix forest LAI was up to 0.5 in May, between 2.5 and 1.5 in early December and between 3.1 and 3.7 till mid-September. In Mixed forest LAI had lower values from 1 to 2.5 during January and higher LAI values ranged between 3 to 6 during mid-September. These logical expressions were used to delineate areas with similar LAI variations by small programs written in ARC Info.

5. Results and discussion

5.1 NDVI-LAI relationship

An exponential relationship (Fig. 3) was obtained between LAI and NDVI. It is given in equation 2.

$$LAI = 0.7116\, e^{3.4264\, NDVI} \qquad \ldots(2)$$

It shows that for NDVI values less than 0.3 there would not be a considerable rise in LAI. However between 0.3 and 0.5 there is exponential increase in LAI against NDVI. After 0.5 NDVI becomes saturated and there is not much increase in it with reference to LAI. However, application of this relationship could improve the LAI in underestimated area, which can be seen.

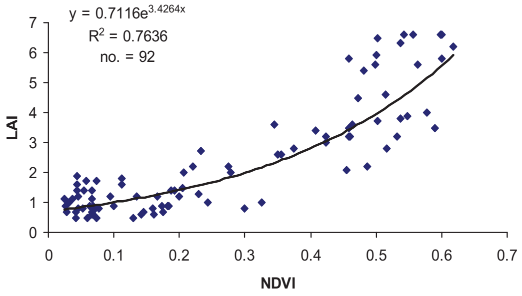

Figure 3: Scatter plot between NDVI and LAI

5.2 LAI temporal profiles

Almost all the profiles showed maximum LAI periods during September to October and minimum LAI periods during April to May (table 1). Similarly, 50% gain in the LAI was achieved till early July but periods of 50% loss occurred from December to January. There is significant difference in LAI values and corresponding periods. These variations reflect the difference in phenophases of major forest communities. Though with a coarse resolution (1 km) data used in the study, it was not possible to find out the exact dates of onset of greenness and senescence and flowering season, we could estimate the periods of different stages of LAI and amplitude of change.

The overall value range for LAI was 7 to 0.3. This value range is reported in similar kind of studies done in deciduous forests (Fensholt et al., 2004; Soudani et al., 2008). LAI values of less than 1 have been reported for deciduous forests in central India (Kale et al., 2005). Maximum LAI from MODIS LAI data for broad leaf forest is estimated to be around 6 which also matches with this study (Tian et al., 2000). All of the tree species showed start of leaf flush during April-May. It is one to two months prior to Monsoon. The onset of leaf flush during peak dry season, before monsoon have been observed in deciduous forest (Kushwaha and Singh, 2005).

5.2.1 Sal (Shorea robusta) forest: Profile for Sal forest shows (Fig.4a) minimum LAI of 1.1 and maximum LAI of 5.8. Thus maximum leaf flush in this forest occurred during late September to mid-October for 31 days. The leaf less period was short, only for 21 days during second half of April. A fourth order polynomial transformation model (equation 3) was fitted for maximum monthly LAI.

$$Y = 0.0137X^4 - 0.3319X^3 + 2.5024X^2 - 5.911X + 5.225 \quad \text{... (3)}$$

Where, X = time (month) and Y= LAI. Gain of 50% in the LAI value was attained until 7th July. Thus within 65 days from 3rd May to 7th July LAI increased by 2.4 (which corresponds to 50% change) whereas same increment was achieved within 74 days till the maximum bloom. During leaf fall period 76 days after 20th October LAI declined by 2.4 till 4th January and further declined to minimum on 12th April through 98 days.

Sal tree shows difference in phenological cycle in different regions. It is reported showing evergreen, semi-evergreen, deciduous, semi deciduous forms in different forests (Singh and Singh, 1992). It has deep root system and exploits water at slower rate. The leaf less period in the deciduous types occurred much earlier and for brief period. Leaf flushing started much before the monsoon. It helps the rapid expansion and development of canopy after rainfall (Kushwaha and Singh, 2005; Singh and Singh, 1988; Singh and Kushwaha, 2005).

5.2.2 Sal mix forest: Sal mixed forest (Fig. 4b) showed maximum LAI of 6.9 for the period of 20 October to 26 November (37 days) and minimum LAI of 0.9 during 25th March to 23 April (29 days). So, maximum leaf flush occurred during late October to November which was almost a month ahead than the pure Sal strands, whereas the leaf less period occurred earlier during late March to April. The increment of 3 in LAI from minimum occurred during 23rd April to 20th July (88 days) and further development to maximum LAI took next 92 days. On the other hand LAI declined by 3 from maximum on 26th November to 11th February within 77 days and continued to fall till the minimum by next 42 days. It shows that the leaf fall process was rapid especially after the 50% leaf loss. A fourth order polynomial transformation model was fitted for maximum monthly LAI values and presented in Equation 4.Where, X = time (month) and Y= LAI.

$$Y = 0.0021X^4 - 0.0914X^3 + 1.0126X^2 - 2.8241X + 2.9207 \quad \text{... (4)}$$

5.2.3 Jamun (Syzygiumcumini) mix forest: Jamun mix forest (Fig. 4c) showed somewhat similar trend with pure Sal as far as temporal periods are concerned but values differed. The maximum blooming occurred during late September to October and corresponding Maximum LAI is 4.2. The leaf less period occurred in April to early May. The 50% increase (from minimum, on 4th May) in the LAI on 8th July and it took 65 days time, but this rise is only of 1.7. By next 78 days LAI reached to maximum. Thus, the leaf development is rapid but the total change (from min to max) is less than Sal forest. After the full leaf flush, 56 days passed till the 50% decline occurred, but for further declination to minimum took 108 days. It shows the later half of the leaf loss process was slower than the first half. A fourth order polynomial transformation model was fitted for maximum monthly LAI values and presented in Equation 5, where X = time (month) and Y= LAI.

$$Y = 0.0014X^4 - 0.0703X^3 - 0.8804X^2 - 3.263X + 4.2061 \quad \text{... (5)}$$

Table 1: Details of LAI statistical parameters and corresponding time periods

Forest Type	Max LAI	Time period (duration in days)	Min LAI	Time period (duration in days)	LAI corresponding to 50% change	Date of 50% LAI gain	Date of 50% LAI loss	Period for 0.1sd change around 50% rise (duration in days)	Period for 0.1sd change around 50% fall(duration in days)
Pure Sal forest	5.8	19th Sept – 20th Oct (31 days)	1.1	12th Apr – 3rd May (21 days)	3.5	7th July	4th Jan	3rd July - 10th July (7 days)	31st Dec – 8th Jan (8 days)
Sal mixed forest	6.9	20th Oct – 26th Nov (37 days)	0.9	25th Mar – 23rd Apr (29 days)	3.9	20th July	11th Feb	13th July – 25th July (12 days)	8th Feb – 15th Feb (7 days)
Jamun mixed forest	4.2	24th Sept – 24th Oct (30 days)	0.8	6th Apr – 4th May (28 days)	2.5	8th July	19th Dec	4th July - 13th July (9 days)	17th Dec – 22nd Dec (5 days)
Bamboo mixed forest	6.2	19th Sept – 22nd Oct (31 days)	1.1	4th May – 26th May (22 days)	3.6	3rd July	10th Jan	30th Jun – 7th July (7 days)	5th Jan – 14th Jan (9 days)
Tinsa mixed forest	6.6	30th Sept – 2nd Nov (33 days)	0.9	4th Apr – 28th Apr (24 days)	3.8	13th July	18th Jan	9th July – 18th July (9 days)	14th Jan – 22nd Jan (8 days)
Lendia mixed forest	3	14th Sept – 7th Oct (23 days)	1	21st Apr – 20th May (29 days)	2	19th July	29th Nov	16th July – 22nd July (6 days)	26th Nov – 2nd Dec (6 days)
Miscellaneous type of forest	3.7	22nd Aug – 15th Sept (24 days)	0.3	22nd Apr – 8th May (16 days)	2	25th Jun	18th Nov	23rd Jun – 28th Jun (5 days)	15th Nov – 21st Nov (6 days)

5.2.4 Lendia (Lagerstroemia parviflora) mix forest: Lendia mix forest (Fig. 4d) did not show as significant variations as Sal and other forest types. The overall change was 3 to 1 with maximum bloom during early October and leaf less period during late April to mid-May. It took about 60 days to increase LAI by 1 from minimum to 19th July and next 57 days to reach the maximum on 14th September. LAI dropped from maximum to half within 53 days on 29th November. It is earlier than any other forest type. The next leaf loss up to minimum was lengthier process which took about 143 days. All other forest types showed the maximum bloom periods longer than leaf less period, except this type. A fifth order polynomial transformation model, presented in Equation 6, defines the LAI trend, where, X = time (month) and Y= LAI.

$$Y = 0.0015\,X^5 - 0.0451\,X^4 + 0.4665\,X^3 - 1.9957\,X^2 + 3.4412\,X - 0.7818 \qquad \text{... (6)}$$

5.2.5 Tinsa (Ougeinia oojeinesis)mix forest: Tinsa mix forest (Fig. 4e) had maximum leaf flush throughout October and leaf less period during April. The LAI variation cycle shows almost equivalent temporal phases during leaf growth and fall. 50% increase in LAI from minimum value i.e. rise of 2.8 occurred by 76 days (28th April to 13th July). This growth continued till maximum on 30th September through 79 days. The 50% decline in LAI took place for 77 days (2nd November and 18th January) and further loss up to minimum LAI was reached by next 76 days. Thus, the first and second half of both the phases took place in similar durations. A fourth order polynomial transformation model was fitted for maximum monthly LAI values and presented in Equation 7.Where, X = time (month) and Y= LAI.

$$Y = 0.0083\,X^4 - 0.2384\,X^3 + 2.1323\,X^2 - 5.9536\,X + 5.0579 \qquad \text{... (7)}$$

5.2.6 Bamboo (Dendrolcalamusstrictus) mix forest: Bamboo mix forest (Fig. 4f) bloomed to maximum during late September to mid-October. This period exactly matches with pure Sal. However the least bloom period occurred during late May. The 50 % increase in LAI value was much rapid than any other forest type. It was within 38 days from 26th May to 3rd July. However, the next development till maximum value was slower and it took 78 days. The 50% decline from maximum LAI took 80 days and further decline occurred in 114 days. This trend of leaf fall phase is similar to Jamun forest but the actual values and periods differ considerably. A fourth order polynomial transformation model, presented in Equation 8, defines the LAI trend. Where, X = time (month) and Y= LAI.

$$Y = 0.0081\,X^4 - 0.229\,X^3 + 2.016\,X^2 - 5.5711\,X + 5.4013 \quad \text{... (8)}$$

5.2.7 Mixed forest: Mixed forest (Fig. 4g) showed highest leaf flush during short period of 24 days during late August and mid-September. The LAI dropped to minimum between late April and first week of May, during leafless conditions. In this type of forest the 50% increase in the LAI occurred within 48 days. This corresponds to rise of 1.7. It took 58 days more to reach the maximum. While during senescence, 64 days passed to reduce the LAI from maximum to 50% LAI from 15th September to 18th November. The further process of LAI reduction was slower and it took 155 days to reduce to minimum value on 22nd April. It seems that the LAI cycle in this type was influenced by herbaceous undergrowth. The rising phase was very rapid and the first phase of LAI reduction is fast. LAI reduced by half till mid-November. The further gradual loss corresponds to reduction due to leaf loss by woody vegetation. Fourth order polynomial transformation model, presented in Equation 9, defines the LAI trend. Where, X = time (month) and Y= LAI.

$$Y = 0.016\,X^4 - 0.3294\,X^3 + 2.1215\,X^2 - 4.3331\,X + 3.3056 \quad \text{... (9)}$$

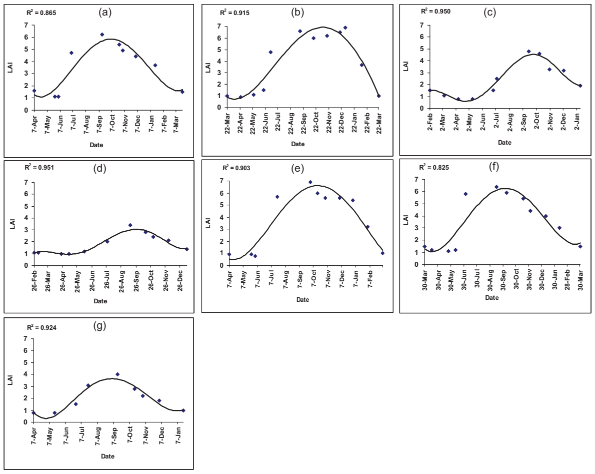

Figure 4: LAI profiles (a) Sal forest, (b) Mix sal forest, (c) Jamun mix forest, (d) Lendia mix forest, (e) Tinsa mix forest, (f) Bamboo mix forest and (g) Mixed forest

5.3 Comparison between leaf flush and leaf fall rates and durations

In case of Sal forest, average leaf flush rate was 4.3 per 15days and new leaves are produced for 170 days (Table 2). This period is longer compared to other types. Leaf fall process is however slower with average rate of 0.35 and lasts for 195 days. Sal mix forest showed leaf flush rate of 0.44 similar to Sal but during fall the rate is almost double than Sal. New leaves were produced for 217 days, which was highest among all types and leaf fall lasted only for 148 days. Jamun forest showed similar durations of leaf flush and leaf fall, but rates of change were quite low. Lendia had lowest rates of change among all. Mix forest had shortest leaf flush period and highest leaf fall duration. Tinsa had highest rates of change during leaf flush but sal mix had highest rate of leaf fall. Tables 3 and 4 give comparison between two species with respect to durations of leaf fall and leaf flush respectively. It shows Sal, Tinsa, Jamun have similar periods of these stages. Sal mix has larger leaf flush periods than fall and shorter leaf fall durations. Lendia and mix forest showed reverse conditions.

5.4 Leaf strategy index

Kushwaha et al. 2005 have stated that the value of LSI should be less than 0.5 for semi-evergreen species and it increases with deciduousness of species. However in this study the index is obtained was more than 1 in most of the cases (Table 2). It is because the change rate of LAI during flush was greater than that of leaf fall. Sal-med showed LSI of 0.71 and Jamun had least LSI of 0.64. LSI is 1.23 for pure strands of Sal, thus revealing the deciduous nature of this species in the area. Highest LSI was shown by Lendia forest.

5.5 Un-paired t-test

It shows almost all the types have distinctly separable LAI during year. However, some types had similar LAI during few months. Sal and Sal-mixed had similar LAI through May to August. Tinsa showed similarity with these two type during June-July. Similar trends in LAI were shown by mix forest and Jamun during July-August, Sal mix and bamboo during September and Lendia and mix forest during October. Lendia also showed similarity in LAI with Jamun during January.

5.6 Mapping of forest communities

A forest community map was prepared using the LAI based criteria (Fig. 5). This map shows that most of the area in the watershed is covered under pure Sal (30.9%) and mixed deciduous (26.6%) forest whereas lowest area was under Lendia mix forest (0.66%). Out of 1025 km^2 area under forest 908 km^2 could be classified in identified communities. Area covered under different forest communities is presented in Table 5.

Table 2: Discrimination analysis among forest types

Forest type	LAI change per 15 days (leaf flush)	LAI change per 15 days (leaf fall)	LSI	Leaf flush period	Leaf fall period
Sal	0.43	0.35	1.23	170	195
Sal mix	0.44	0.62	0.71	217	148
Lendia mixed	0.23	0.15	1.53	140	225
Jamun mixed	0.28	0.44	0.64	173	192
Bamboo mixed	0.47	0.37	1.27	149	216
Tinsa mixed	0.51	0.53	0.96	162	203
Mixed forest	0.41	0.30	1.37	130	235
Average	0.40	0.40	-	163	202

Table 3: Comparison among forest type with respect to leaf flush period by simple ratio

Periods in numerator → Periods in denominator ↓	SalForest	SalmixForest	Lendia mixed Forest	Jamun mixed Forest	Bamboo mixed Forest	Tinsa mixed Forest	Mix Forest
Sal Forest	1.0	1.3	0.8	1.0	0.9	1.0	0.8
Sal mixed Forest	0.8	1.0	0.6	0.8	0.7	0.7	0.6
Lendia mixed Forest	1.2	1.6	1.0	1.2	1.1	1.2	0.9
Jamun mixed Forest	1.0	1.3	0.8	1.0	0.9	0.9	0.8
Bamboo mixed Forest	1.1	1.5	0.9	1.2	1.0	1.1	0.9
Tinsa mixed Forest	1.0	1.3	0.9	1.1	0.9	1.0	0.8
Mix Forest	1.3	1.7	1.1	1.3	1.1	1.2	1.0

Table 4: Comparison among forest type with respect to leaf fall period by simple ratio

Periods in numerator → Periods in denominator ↓	SalForest	Salmixed Forest	Lendia mixed Forest	Jamun mixed Forest	Bamboo mixed Forest	Tinsa mixed Forest	Mix Forest
Sal Forest	1.0	0.8	1.2	1.0	1.1	1.0	1.2
Sal mixed Forest	1.3	1.0	1.5	1.3	1.5	1.4	1.6
Lendia mixed Forest	0.9	0.7	1.0	0.9	1.0	0.9	1.0
Jamun mixed Forest	1.0	0.8	1.2	1.0	1.1	1.1	1.2
Bamboo mixed Forest	0.9	0.7	1.0	0.9	1.0	0.9	1.1
Tinsa mixed Forest	1.0	0.7	1.1	0.9	1.1	1.0	1.2
Mix Forest	0.8	0.6	1.0	0.8	0.9	0.9	1.0

Table 5: Area under different forest types in watershed

Forest type	Major species covered	Area covered (km^2)	Percentage of forest cover (%)
Pure Sal Forest		317.1	30.9
Sal mixed Forest	Sal, Jamun, Lendia, Gonta, Tinsa	215.8	21
Jamun mixed Forest	Lendia, Sal, Lasoda, Bansa, Jamun	32.8	3.2
Lendia mixed Forest		6.8	0.66
Tinsa mixed Forest	Tinsa, Sal Jamun, Baheda	14.5	1.4
Bamboo mixed Forest	Bamboo, Harra, Kumbhi, Kari, Gunja, Dhawra	48.4	4.7
Mixed forest	Sal, Jamun, Lendia, Bamboo, Gonta	273	26.6
Total		908.4	88.46

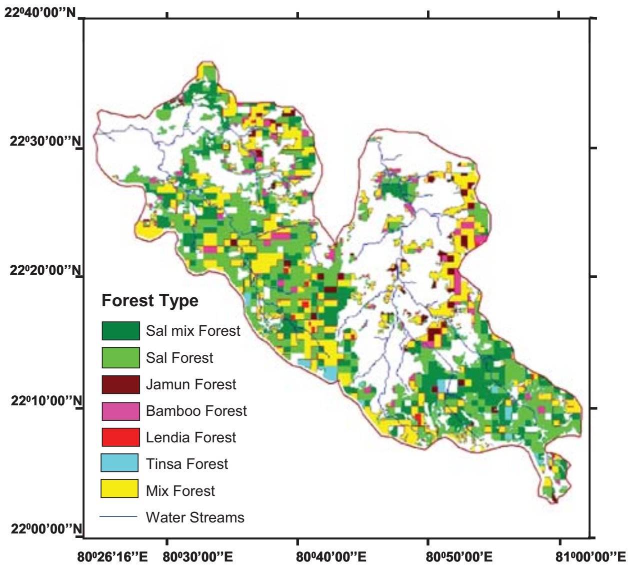

Figure 5: Forest community map derived using LAI profiles

5.7 Comparison of MODIS LAI with in situ measurements

A good correlation between MODIS LAI and in situ measurement was obtained (Fig. 6). The relationship is almost linear and R square value is significantly high i.e. 0.87.

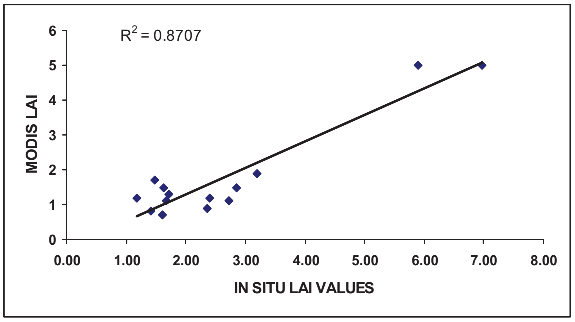

Figure 6: Comparison between MODIS LAI and in situ LAI values

6. Discussion

Present study highlights the application of the satellite remote sensing which provides high temporal data for the phenological analysis. Amplitude and timing of change in the various phenological parameters for a particular type of forest community is very limited and highly useful for modeling the water balance and water management in the forest system. Interception losses, evaporation, transpiration, surface water availability for infiltration etc. are some of the hydrological processes affected due to changes in the phenology. Limitation of the present work is that results are site specific.

7. Conclusions

The phenological phases of forest could be retrieved from MODIS LAI through annual profiles. LAI profiles were found suitable for the depictions of phenological parameters like leaf fall, leaf flush periods, rates of changes during leaf flush and fall, changes corresponding to halfway changes during flush and fall. The seasonal climatic changes drive the phenological response in all the types throughout year. Almost all the communities showed maximum leaf flush duration during September-October and leaf less period during April-May. However there was considerable difference in the exact duration, amplitude and rate of change in LAI. The comparison among communities revealed that some communities had similarity with respect to one parameter but they were distinctly different in case of other. Sal forest in the area is of deciduous nature but leaf flush duration is longer. Lendia and mix forest showed longer leaf less periods. Coarse spatial resolution data found suitable to obtain the time periods for different LAI stages for different forest communities.

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