



# PHENOLOGY OF SELECTED TREE SPECIES AT KANPUR, INDIA: SEASONAL PATTERNS AND THEIR RELATIONSHIP WITH CLIMATIC FACTORS

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## Abstract

Plant phenology deals with the timing and seasonal recurrence of biological events and their relationship with environmental conditions. In trees, phenological events such as leaf emergence, leaf expansion, leaf fall, flowering, fruit development and fruit maturation represent important components of annual plant functioning. These events influence photosynthetic productivity, reproduction, resource allocation, pollination, seed dispersal and ecosystem functioning. The present paper examines the phenological characteristics of selected tree species occurring in and around Kanpur, Uttar Pradesh, India, with particular emphasis on seasonal patterns and their relationship with climatic variables. The study adopts a literature-based analytical approach supported by long-term climatological information for Kanpur and published studies on tropical tree phenology in India.

Kanpur experiences pronounced seasonal climatic variation. India Meteorological Department climatological records for 1981–2010 indicate an annual mean rainfall of 648.5 mm, with rainfall strongly concentrated during the southwest monsoon. July and August receive mean monthly rainfall of 185.3 and 191.7 mm, respectively, while the mean maximum temperature reaches 39.8°C in May. Such strong seasonality creates an ecologically important climatic framework for studying vegetative and reproductive phenology. Published research on Indian tropical trees demonstrates that flowering, fruiting and leafing vary considerably among species and that their timing may be associated with temperature, rainfall, moisture availability, photoperiod and solar radiation.

The available evidence indicates that tropical tree species do not exhibit a single uniform phenological strategy. Deciduous species may concentrate leaf shedding and leaf flushing around periods of seasonal water stress and subsequent moisture availability, whereas evergreen and semi-evergreen species may maintain foliage for longer periods with less pronounced leafless phases. Flowering may occur before, during or after leaf flushing, and fruiting duration may differ considerably among species. The paper discusses these patterns in relation to the seasonal climate of Kanpur and evaluates their ecological implications for urban vegetation, biodiversity conservation, restoration, seed collection and climate-change monitoring. The study concludes that systematic long-term phenological monitoring in Kanpur would provide valuable baseline information for detecting future changes in plant–climate relationships.



**Keywords:** *Phenology, tree phenology, leaf flushing, leaf fall, flowering, fruiting, climate, rainfall, temperature, Kanpur, India.*

## 1. Introduction

Phenology is the study of the timing of recurring biological events and their relationship with seasonal environmental variation. In plants, these events include bud development, leaf emergence, leaf expansion, leaf senescence, leaf fall, flowering, fruit development and seed maturation. Phenological processes are fundamental to plant ecology because they determine when plants acquire photosynthetic capacity, allocate resources towards reproduction and interact with other organisms.

Trees provide particularly useful systems for phenological research because their life cycles are strongly influenced by seasonal environmental conditions and because individual trees can be monitored over extended periods. The timing of leaf development determines the duration of active photosynthesis, while flowering and fruiting determine the availability of reproductive resources to pollinators and seed dispersers. Consequently, phenological variation can influence not only individual plant fitness but also broader ecosystem processes.

Phenology is especially significant in tropical and subtropical regions where seasonal changes in rainfall and temperature can strongly influence plant growth. Unlike many temperate systems in which temperature and photoperiod are dominant seasonal cues, tropical trees may respond to complex combinations of water availability, temperature, solar radiation, photoperiod and antecedent climatic conditions.

India provides an important geographical setting for studying tree phenology because its vegetation occurs across strong climatic gradients. The country includes evergreen forests, moist deciduous forests, dry deciduous forests, semi-arid vegetation and montane ecosystems. Tree species occupying these environments have consequently developed diverse phenological strategies.

A major study by Singh and Kushwaha on tropical deciduous trees in India demonstrated substantial diversity in flowering and fruiting schedules. Their investigation of nine tree species over two annual cycles revealed five broad flowering types: summer flowering, rainy-season flowering, autumn flowering, winter flowering and dry-season flowering. They further found considerable variation in the interval between leaf flushing and flowering and in the duration of fruiting.

These findings are important because they demonstrate that tree phenology cannot be explained simply by assigning all species to a common seasonal pattern. Even species growing within the same climatic region may exhibit different combinations of vegetative and reproductive events.

Kanpur, located in the Indo-Gangetic Plain of Uttar Pradesh, represents a suitable setting for examining these relationships. The region experiences a strongly seasonal climate, with relatively cool winters, rapidly increasing temperatures during spring, very hot conditions during the pre-monsoon period and concentrated rainfall during the southwest monsoon.

According to India Meteorological Department climatological data for 1981–2010, the mean daily maximum temperature in Kanpur rises from 22.3°C in January to 39.8°C in May. Mean daily minimum temperature increases



from 8.2°C in January to 27.2°C in June. Rainfall is highly seasonal, with mean monthly rainfall reaching 185.3 mm in July, 191.7 mm in August and 138.1 mm in September. Annual mean rainfall is 648.5 mm.

The climatic characteristics of Kanpur therefore create a strong environmental gradient across the year. The period from approximately March to June is characterized by increasing heat and relatively limited rainfall, whereas July to September represents the principal period of water availability. October marks a transition towards a cooler and drier period, followed by relatively dry winter months. Such climatic transitions may provide important environmental cues for the timing of phenological events.

The study of tree phenology in such a seasonal environment has both theoretical and applied significance. From an ecological perspective, it contributes to understanding how plants synchronize growth and reproduction with environmental conditions. From a practical perspective, knowledge of flowering and fruiting periods is valuable for seed collection, restoration, urban forestry, biodiversity conservation and management of green spaces.

Phenology has also gained importance in the context of climate change. Because many biological events are environmentally sensitive, changes in their timing may provide early biological evidence of changing climatic conditions. Long-term phenological records can therefore establish baselines against which future observations can be compared.

Recent research in India illustrates the value of such long-term monitoring. A study of approximately 719 tree individuals representing 95 species in a lowland evergreen forest of the Western Ghats monitored vegetative and reproductive phenology from April 2021 to September 2023. The study found significant seasonal patterns and relationships between phenological events and climatic variables. Leaf flushing, flowering and fruiting showed different associations with temperature, humidity and rainfall-related variables, emphasizing that different phenophases may respond differently to climate.

Similarly, research in the Eastern Himalaya involving long-term monitoring of hundreds of individual trees has demonstrated substantial seasonal variation in leaf, flower and fruit phenology and highlighted the importance of environmental variables in shaping phenological patterns.

The present paper therefore examines the phenology of selected tree species from a conceptual and comparative perspective, using Kanpur's climatic characteristics as the geographical framework. Because systematic field observations for the present study were not available, the paper does not fabricate numerical field results. Instead, it synthesizes established scientific evidence and develops an analytical interpretation relevant to the Kanpur environment.

## **2. Review of Literature**

### **2.1 Concept and Ecological Importance of Phenology**

Phenology provides an integrated measure of the interaction between organisms and their environment. The timing of a biological event reflects both endogenous developmental processes and external environmental cues.



In trees, the principal phenological events can broadly be divided into vegetative and reproductive phases. Vegetative phenology includes leaf flushing, leaf expansion, shoot development, senescence and leaf fall. Reproductive phenology includes flowering, fruit formation, fruit maturation and seed dispersal.

The ecological importance of phenology arises partly from its role in resource allocation. Leaf development increases the photosynthetic capacity of the tree, whereas flowering and fruiting require substantial investment in reproductive structures. Species must therefore synchronize these activities with periods that maximize their probability of survival and reproduction.

## **2.2 Phenology of Tropical Deciduous Trees**

Singh and Kushwaha conducted one of the important quantitative investigations of tree phenology in an Indian tropical dry deciduous forest. They monitored nine species and recorded leaves, flowers and fruits on tagged twigs over two annual cycles. The study showed that flowering relative to leaf flushing produced five distinct flowering types.

Their results indicated that fruiting duration varied substantially according to flowering season. Dry-season and winter-flowering species had relatively short fruiting periods, whereas rainy-season and autumn-flowering species generally had longer fruiting periods. Summer-flowering species could maintain fruit development for an especially long period.

The authors interpreted these patterns as adaptations to the monsoonal climate. The relationship between leafless periods and reproductive timing suggested that trees partition resources between vegetative growth and reproduction in ways that reflect seasonal environmental constraints.

## **2.3 Climate as a Driver of Phenology**

Temperature, rainfall and water availability are among the most frequently investigated environmental factors affecting plant phenology.

Temperature can influence physiological processes involved in bud development, leaf expansion, flowering and fruit maturation. However, the effect of temperature may vary between species and between phenophases.

Rainfall is particularly important in seasonal tropical ecosystems where water availability can change dramatically across the year. The onset of rainfall may stimulate vegetative growth in drought-deciduous trees, although rainfall is not necessarily the sole or universal trigger of leaf flushing.

Recent research in the Western Ghats demonstrates the complexity of these relationships. A study involving 719 individuals from 95 tree species found that leaf flushing, flowering and fruiting showed different associations with climatic variables. Leaf flushing was positively associated with maximum relative humidity and negatively associated with maximum temperature and number of rainy days, while fruit production showed a positive association with maximum temperature and a negative association with rainy days.

These findings reinforce the importance of analysing individual phenophases rather than assuming that all plant developmental processes respond identically to climate.

## **2.4 Long-Term Phenological Monitoring**

Long-term observations are particularly valuable because a single year of observations cannot adequately distinguish normal seasonal variability from long-term environmental change.

A recent Indian study emphasized that phenological monitoring can provide important information about changing ecological conditions and can support conservation planning. The use of long-term datasets also allows researchers to identify changes in the onset, duration and synchronization of phenological events.

The increasing availability of citizen-science observations and publicly available photographs provides an additional source of phenological information. Recent research on three widespread tropical tree species in India demonstrated that publicly available images and data repositories can be used to examine geographical patterns in flowering phenology.

## **3. Objectives of the Study**

The principal objectives of the present study are:

To examine the phenological characteristics of selected tree species relevant to the Kanpur region.

To identify major seasonal patterns in leaf flushing, leaf fall, flowering and fruiting.

To evaluate the potential relationship between phenological events and temperature and rainfall.

To compare phenological strategies among evergreen, semi-evergreen and deciduous tree species.

To assess the ecological significance of phenological variation.

To develop a scientific framework for future long-term phenological monitoring in Kanpur.

To examine the relevance of tree phenology for biodiversity conservation, urban forestry and climate-change assessment.

## **4. Materials and Methods**

### **4.1 Study Area**

Kanpur, Uttar Pradesh, was selected as the geographical framework for the study. The city lies within the Indo-Gangetic Plain and experiences a strongly seasonal climatic regime.

Long-term climatological data published by the India Meteorological Department for the 1981–2010 period provide the climatic background used in this analysis. Annual mean rainfall is 648.5 mm. July and August are the wettest months, receiving 185.3 and 191.7 mm of mean rainfall, respectively, while September receives 138.1 mm. Rainfall declines sharply after the monsoon, with only 33.9 mm in October, 3.4 mm in November and 2.1 mm in December.

The temperature regime is equally seasonal. Mean maximum temperature is 22.3°C in January, rises to 39.8°C in May and remains high at 39.0°C in June. It subsequently declines during the monsoon and post-monsoon periods.

These conditions create four broad climatic phases:



cool winter;  
warming spring;  
hot pre-monsoon summer; and  
monsoon and post-monsoon period.

Such seasonality provides a useful ecological framework for interpreting tree phenology.

#### **4.2 Selection of Tree Species**

For future field validation, commonly occurring tree species representing different phenological strategies may be selected. Suitable candidates include:

*Azadirachta indica* A.Juss. — Neem

*Ficus religiosa* L. — Peepal

*Ficus benghalensis* L. — Banyan

*Mangifera indica* L. — Mango

*Syzygium cumini* (L.) Skeels — Jamun

*Dalbergia sissoo* Roxb. — Shisham

*Albizia lebbeck* (L.) Benth. — Siris

*Delonix regia* (Bojer ex Hook.) Raf. — Gulmohar

The final selection should be based on actual occurrence, abundance and accessibility within the selected Kanpur study sites.

#### **4.3 Phenophases**

Four major phenophases are proposed for monitoring:

Leaf flushing

The appearance and expansion of new leaves should be recorded from the first visible flush through completion of major leaf development.

Leaf fall

The beginning, peak and completion of leaf shedding should be recorded, with special attention to strongly deciduous species.

Flowering

Flowering should be divided into initiation, peak flowering and termination.

Fruiting

Fruit development should be recorded from initial fruit formation through maturation and fruit fall.

#### **4.4 Observation Frequency**

A future field investigation should preferably use weekly or fortnightly observations. Fortnightly monitoring is particularly suitable for a year-long baseline study because it provides a balance between observation intensity and practical feasibility.

For each individual, observations should be recorded using a standardized data sheet. The same phenological definitions should be maintained throughout the observation period.

#### **4.5 Climatic Variables**

The following variables should be considered:

maximum temperature;  
minimum temperature;  
mean temperature;  
monthly rainfall;  
number of rainy days;  
relative humidity, where available;  
soil moisture, where feasible; and  
solar radiation, where reliable data are available.

#### **4.6 Analytical Approach**

Phenological observations should be summarized by onset date, peak date, termination date and duration.

Where sufficient observations are collected, correlation and regression analyses may be employed to examine associations between climatic variables and phenological timing.

However, because the present paper does not contain original field observations, no fabricated correlation coefficients, p-values or regression coefficients are reported.

### **5. Results and Discussion**

#### **5.1 Seasonal Climate of Kanpur as a Phenological Framework**

The climatological profile of Kanpur indicates that plants experience a substantial seasonal transition in temperature and water availability. Mean maximum temperature increases from 22.3°C in January to 39.8°C in May, while rainfall increases sharply during the monsoon, reaching 185.3 mm in July and 191.7 mm in August.

This climatic sequence can potentially influence the annual organization of tree phenophases.

The hot and relatively dry pre-monsoon period may impose water stress on species with limited access to soil moisture. Deciduousness can therefore represent an important mechanism for reducing transpirational demand. Conversely, the onset of monsoon rainfall increases water availability and can provide favourable conditions for renewed vegetative growth.

This interpretation is consistent with research from Indian tropical deciduous forests in which leaf phenology was associated with seasonal drought and moisture conditions.

#### **5.2 Leaf Phenology**

Leaf flushing represents the beginning of a period of renewed vegetative activity. In deciduous species, it frequently follows a period of leaflessness, whereas evergreen species may show gradual replacement of old foliage.

The strong seasonal climate of Kanpur suggests that different species may use different strategies. A drought-deciduous species may shed leaves before or during the hot pre-monsoon period and subsequently produce a new



flush when environmental conditions become favourable. An evergreen species may maintain foliage throughout much of the year, thereby avoiding the sharp transition between leafed and leafless states.

The ecological significance of these strategies lies in their relationship to water conservation and carbon acquisition. Maintaining leaves during a dry period can permit continued photosynthesis but requires water, while shedding leaves reduces transpirational loss but temporarily reduces carbon assimilation.

Indian tropical phenological research has demonstrated that the extent of deciduousness is related to the duration of the leafless period and to the timing of subsequent reproductive events.

### **5.3 Flowering Phenology**

Flowering is likely to display considerable interspecific variation in Kanpur. The seasonal climate permits the possibility of flowering during several different periods of the annual cycle.

The Indian literature provides strong evidence for this diversity. Singh and Kushwaha identified five flowering patterns in tropical deciduous trees and showed that flowering could occur on foliated or leafless shoots depending on species and season.

This diversity may have important consequences for pollination ecology. Species flowering at different times reduce direct competition for pollinators and can provide floral resources across a broader portion of the annual cycle.

At the same time, flowering during periods of reduced rainfall may be advantageous for some species because dry weather can facilitate pollinator activity and pollen transfer. The exact ecological benefit, however, depends upon pollination syndrome and species-specific reproductive biology.

### **5.4 Fruiting Phenology**

Fruiting represents the transition from successful pollination to seed development and dispersal. Its timing is therefore influenced partly by flowering date and partly by the physiological requirements of fruit maturation.

The literature indicates that fruiting duration can vary dramatically among tropical tree species. In the Indian dry deciduous forest studied by Singh and Kushwaha, fruiting duration ranged from only a few months in some dry-season and winter-flowering species to considerably longer periods in summer-flowering species.

For Kanpur, fruit maturation may be particularly important in relation to the monsoon. Species whose fruits mature around the rainy season may benefit from increased soil moisture during subsequent seedling establishment, whereas species dispersing seeds during dry periods may depend on different regeneration mechanisms.

### **5.5 Relationship between Temperature and Phenology**

Temperature is an important environmental variable for plant development. Increasing temperature during spring may accelerate developmental processes, although excessive temperature can also increase evaporative demand and physiological stress. Kanpur's mean maximum temperature of 39.8°C in May indicates that the pre-monsoon period represents a substantial thermal challenge for vegetation. The response of trees to this period is likely to depend upon species-specific physiological characteristics. Deciduous species may reduce water loss through leaf shedding, whereas evergreen species may depend on deeper water access, physiological regulation or other adaptations. Recent Indian research confirms that different phenophases may have different temperature relationships. In a Western

Ghats tree community, leaf flushing and flowering showed relationships with temperature and humidity that differed from those observed for fruiting.

Thus, temperature should be considered as a phenophase-specific driver rather than as a universal predictor.

### **5.6 Relationship between Rainfall and Phenology**

Rainfall is particularly relevant in Kanpur because annual rainfall is strongly concentrated in a few months. July and August together account for a large proportion of the annual rainfall.

The arrival of monsoon rainfall can increase soil moisture and reduce drought stress. For moisture-sensitive species, this may stimulate leaf production and shoot development.

However, published evidence indicates that rainfall does not have a uniform influence on all phenological events. The Western Ghats study found contrasting relationships between rainfall-related variables and leaf flushing, flowering and fruiting.

Therefore, a future Kanpur field study should analyse rainfall not merely as annual total precipitation but as a time-specific variable. The onset of rainfall, rainfall in the preceding month and cumulative rainfall over several weeks may be more informative for understanding phenological transitions.

### **5.7 Evergreen and Deciduous Strategies**

The comparison between evergreen and deciduous species provides an important conceptual basis for understanding phenological diversity.

Evergreen trees may maintain leaves for extended periods and replace foliage gradually. Their strategy permits a relatively continuous photosynthetic period when environmental conditions remain suitable.

Deciduous species, in contrast, may concentrate growth within a shorter favourable season. Leaflessness reduces water consumption during stressful periods but limits photosynthetic activity.

Singh and Kushwaha's work demonstrated that Indian tropical trees possess a wide range of deciduousness, from semi-evergreen forms to species experiencing several months without leaves.

This diversity should be expected within an urban and peri-urban environment such as Kanpur, where species from different ecological origins are frequently planted together.

### **5.8 Phenology and Urban Environment**

Kanpur is a major urban centre, and urban conditions may modify the phenological behaviour of trees.

Urban trees can experience:

- higher local temperatures;
- altered soil moisture;
- irrigation;
- air pollution;
- artificial night lighting;
- restricted rooting volume;
- soil compaction; and
- increased human disturbance.



These factors can modify phenological timing relative to trees growing under less disturbed conditions. Consequently, future studies should distinguish between naturally occurring trees, irrigated landscape trees and roadside plantations whenever possible.

## **6. Ecological Significance**

### **6.1 Pollination**

Flowering periods determine when nectar, pollen and other floral resources are available. Temporal differences among tree species can influence pollinator abundance and activity.

### **6.2 Seed Dispersal**

Fruit availability determines the timing of food resources for frugivorous birds and mammals. Consequently, fruiting phenology can influence animal movement and seed dispersal.

### **6.3 Carbon Assimilation**

Leaf emergence marks an increase in photosynthetic surface area. Conversely, leaf fall represents a reduction in canopy photosynthetic activity and transfers organic matter to the soil.

### **6.4 Nutrient Cycling**

Seasonal litter production resulting from leaf fall contributes to decomposition and nutrient cycling. Differences in the timing of leaf fall can therefore influence the seasonal availability of organic matter.

### **6.5 Forest and Urban Management**

Knowledge of flowering and fruiting calendars can help determine appropriate periods for seed collection, propagation and restoration planting.

### **6.6 Climate-Change Monitoring**

Phenological shifts can provide biologically meaningful indicators of environmental change. Long-term observations may reveal whether flowering, leaf flushing or fruit maturation is occurring progressively earlier or later.

## **7. Implications for Future Research in Kanpur**

A major limitation of the present study is the absence of original field observations. The paper therefore provides a literature-based scientific synthesis rather than claiming a completed experimental field survey.

A systematic field investigation in Kanpur should ideally monitor selected trees for at least three consecutive years.

A longer period would be preferable because phenological events can vary substantially between years.

The recommended design would include:

8–12 common tree species;

at least 5–10 individuals of each species;

fortnightly observations;

standardized phenological categories;

simultaneous climatic measurements;



GPS-based site documentation;

photographic records;

annual repetition; and

statistical analysis of climate–phenology relationships.

Where possible, researchers should also record irrigation, soil type, canopy exposure and anthropogenic disturbance.

Such a dataset could eventually allow the development of a Kanpur Tree Phenological Calendar.

### **8. Limitations of the Study**

The principal limitation is that the present paper is based on published scientific literature and available climatological information rather than newly collected field observations.

Accordingly, the study does not claim that a particular tree species flowered or produced leaves on a specific date in Kanpur during a particular year.

Similarly, no artificial numerical dataset has been generated to produce statistical significance. This distinction is important because fabricated field observations would compromise the scientific validity of the research.

The climatic information used for Kanpur is based on IMD climatological normals for 1981–2010. These provide an established long-term climatic baseline but do not by themselves represent every year's contemporary climatic conditions.

Future research should therefore combine updated climatic observations with direct field phenology.

### **9. Conclusion**

Phenology provides an important framework for understanding the seasonal functioning of trees and their responses to environmental variation. The seasonal climate of Kanpur, characterized by cool winters, a rapidly warming spring, extremely hot pre-monsoon conditions and concentrated monsoon rainfall, provides an ecologically meaningful setting for studying tree phenology.

The climatological data demonstrate substantial seasonal variation in both temperature and rainfall. Mean maximum temperature reaches 39.8°C in May, while mean monthly rainfall reaches 185.3 mm in July and 191.7 mm in August. These environmental transitions can potentially influence the timing of leaf flushing, leaf fall, flowering and fruiting.

Evidence from Indian tropical forests demonstrates that tree species exhibit highly diverse phenological strategies. Flowering may occur during different seasons and may be associated with different stages of leaf development. Fruiting duration can also vary substantially among species.

Recent research further demonstrates that temperature, rainfall, humidity and other climatic factors may influence different phenophases in different ways. Consequently, tree phenology should be interpreted as the outcome of interactions between species-specific biological characteristics and multiple environmental cues rather than as a simple response to one climatic variable.



For Kanpur, systematic phenological monitoring would provide a valuable scientific baseline. Such information could support urban forestry, biodiversity conservation, restoration programmes, seed collection and ecological education. More importantly, repeated observations over several years could establish whether the timing and duration of important biological events are changing in response to climatic variability.

The development of a long-term tree phenology database for Kanpur would therefore represent a useful contribution to regional plant ecology. It would connect local botanical observations with broader questions concerning climate variability, ecosystem functioning and biological adaptation.

In conclusion, the phenological behaviour of trees in Kanpur should be understood as a dynamic interaction between seasonality, water availability, temperature, species-specific traits and reproductive strategy. Future field-based research should build upon this conceptual framework through standardized, multi-year observations and quantitative climate–phenology analysis.

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