Evaluating Dendroclimatic Relationships of Plantation-Grown Teak (*Tectona grandis* L.f.) in Thrissur, Kerala

Abstract

Dendroclimatology, a specialized branch of dendrochronology, offers critical insights into forest plantation management under climate change impacts, enabling historical climate reconstruction, growth forecasting, adaptive strategies, and carbon sequestration assessments through tree ring analysis. This study explored the climatic influences on teak (*Tectona grandis* L.f.) growth in selected plantation sites within the Thrissur district, Kerala. Tree samples spanning 1959–2009 were collected from three randomly chosen plantation sites. Tree ring widths were measured and cross-dated using the LINTAB-6 and TSAP-Win software. At the same time, the ARSTAN program was employed for standardization to isolate climate-related signals by eliminating non-climatic noise. The derived ring width indices (RWI) were subjected to correlation analysis. PAST software analysed the relationship between RWI values and climate parameters, specifically monthly rainfall and temperature, based on CRU TS V.3.21 dataset data. Results revealed a positive correlation between rainfall and tree growth, whereas temperature exhibited a negative correlation. Statistical metrics, including the signal-to-noise ratio (SNR) and expressed population signal (EPS), validated the dendroclimatic reliability of the study site. These findings underscore the potential of dendroclimatology in understanding climate-growth dynamics and its application in sustainable forest management. The observed climate-growth relationships can aid in developing climate adaptation strategies for teak plantations by guiding site selection, optimizing plantation management practices, and predicting future growth responses under changing climatic conditions. This research provides valuable insights for policymakers and forest managers aiming to enhance climate resilience in plantation forestry.

Keywords: *Tectona grandis*, Dendroclimatology, dendroclimatic potential, climate, Thrissur, Teak wood

Introduction

The global climatic conditions are constantly changing. Climate change is a pressing global issue that profoundly impacts the delicate balance of our planet. Its effects ripple with significant consequences through various sectors such as agriculture, fisheries, and forestry, especially in tropical and subtropical regions. Therefore, gaining a comprehensive understanding of climate change and its underlying causes is essential for addressing the challenges faced by our society.

To comprehend the current trajectory of climate change, it is necessary to consider the insights provided by past climatic conditions. The study of climate patterns predating the instrumental record is known as Paleoclimatology (Bradley, 1999). Unfortunately, instrumental records only span 100-150 years, rendering them insufficient for examining climatic conditions dating back millions of years. Sources such as ice cores, lake sediments, pollen grains, and tree rings are utilized to bridge this gap. Among these, tree rings are a pivotal proxy for extending knowledge beyond the instrumental climate record (Cook *et al*., 2010)

The study of past climates through tree rings as a proxy is known as dendroclimatology, a branch of dendrochronology (Fritts, 1976). This field employs various methods to assess the impact of climatic variables (such as temperature, precipitation, and relative humidity) on tree ring characteristics (including ring width and wood density) over specific historical periods supported by instrumental records. The climatic information before the instrumental record can be determined using response function analysis.

The growth of a tree is influenced by climate variables, including precipitation, temperature, sunlight, and relative humidity, in addition to non-climatic variables like insect pest influence and soil nutrient characteristics. These factors collectively shape tree growth. Each year, a tree produces one annual ring. This annual ring is composed of one light ring and one dark ring. The formation of these annual rings, year after year, reflects the tree's growth, strongly influenced by the prevailing climatic conditions. Trees form wider rings in favourable weather, producing narrower rings during unfavourable or stressful conditions. When faced with particularly challenging circumstances, trees may develop irregular, missing, or false rings. By carefully analyzing the characteristics of these rings, dendroclimatologists can gain insights into the climate conditions that existed during the tree's growth period. This is why tree rings serve as a valuable proxy for detecting past climates.

Teak stands out as one of the best tree species for conducting dendroclimatological studies. The ideal conditions for teak growth include an annual rainfall ranging from 800 to 3750 mm, maximum and minimum temperatures of 39-43°C and 13-17°C, respectively, and an elevation below 1000 m (Zaw *et al*., 2020). Teak is a ring-porous species, making it exceptionally well-suited for dendroclimatological research due to its clear annual ring patterns. Once tree ring samples are collected and prepared, the next step is to develop chronologies. These chronologies should exhibit a high signal-to-noise ratio (SNR), Expressed Population Signal (EPS), a substantial common variance, and mean sensitivity (MS). Additionally, they should feature a high standard deviation, low autocorrelation, and other essential characteristics (Fritts, 1976).

The primary aim of this study is to evaluate the dendroclimatic potential of teak trees grown in selected sites for reconstructing precipitation and temperature data. To achieve this, the following objectives were considered: a) develop and analyze the tree ring chronologies of teak in Thrissur district, b) assess the relationship between tree growth and climate, and c) determine the dendroclimatic potential of ring width and wood density for the reconstruction of temperature and precipitation.

Materials and Methods

Study Site and Sample Preparation

The primary objective of this research was to develop and analyze tree-ring chronologies of teak (*Tectona grandis* L.f.) plantations in Thrissur district, Kerala. This was undertaken to assess the dendroclimatic potential of ring-width measurements to reconstruct historical temperature and precipitation patterns and explore the connections between tree growth and climatic variables. Tree specimens were randomly sampled from carefully chosen plantation sites for this purpose.

Thrissur's climate is defined by a tropical monsoon system encompassing three main seasons. The summer season, marked by hot and humid conditions, lasts from March to May, followed by the southwest monsoon from June to September, bringing heavy rainfall. Additional precipitation occurs during the northeast monsoon from October to November. The winter season, characterized by cooler temperatures, extends from December to February. Thrissur experiences significant annual rainfall, averaging around 3000 mm, with an average temperature of approximately 27°C.

Teak tree samples, collected as basal discs from the selected plantation sites, were transported to the laboratory for further analysis. The discs were first prepared by levelling their top surfaces using a hand planer to create a smooth and even surface. To reveal the annual growth rings for ring-width measurement, the surfaces were polished sequentially with sandpapers of varying grit sizes, including 60, 80, 150, 220, 320, and 400, and applied to three to four radii on each disc. For a detailed examination of vessel characteristics, finer grit sandpapers of grades 600, 800, 1000, and 1500 were used for additional polishing. Finally, the discs were cleaned using a gentle water jet to expose the vessel lumens, ensuring accurate observations and measurements.

This careful and systematic preparation of samples was essential for ensuring the accuracy and reliability of the dendroclimatic analyses performed during the study.

Ring width measurement

Tree-ring measurement demands high precision and consistency, achieved using the LINTAB-6 system. LINTAB-6 is a robust, user-friendly digital positioning table designed to measure tree-ring widths in stem discs and increment cores. Its durability and splash-proof design make it well-suited for tree-ring analysis. Combined with TSAP-Win software, LINTAB-6 enables detailed and accurate dendroclimatic studies.

In this study, tree discs were polished and carefully positioned on the LINTAB-6 platform for measurement. Tree-ring widths, defined as the perpendicular distance between the latewood of two consecutive growth years, were measured along selected radii. A stereomicroscope (Motic) equipped with a digital camera was used to capture real-time images of the growth rings. The platform allowed precise adjustment of the wood discs, enabling measurements of annual rings from the pith to the bark. These measurements were digitally recorded to a precision of 0.001 mm using TSAP-Win software.

TSAP-Win is an advanced software system designed for tree-ring analysis, encompassing the entire process from measurement to sequence evaluation. It provides extensive visual and statistical tools, along with database integration. After polishing, the growth rings on each disc were numbered and matched across three to four radii. The digital camera attached to the stereomicroscope projected images of the selected growth rings onto a computer screen. The ring widths were measured using the LINTAB-6 system, and the data for each growth year were digitally recorded with an accuracy of 0.001 mm. These measurements facilitated the calculation of growth rates and provided the foundation for further dendroclimatic analysis.

Cross-dating

Cross-dating is a fundamental procedure in dendrochronology, essential for accurately determining the formation year of each tree ring while addressing errors such as missing or false rings. The conventional "skeleton plotting" method, as outlined by Stokes and Smiley (1968), provides reliable results but is labor-intensive. To enhance efficiency, modern statistical methods supported by specialized software, referred to as "software-assisted cross-dating," are now widely employed. Cross-dating relies on the principle that trees generally form one growth ring per year; however, environmental stress can result in missing rings, while fluctuating conditions may produce false or double rings due to alternating earlywood and latewood growth. Successful cross-dating depends on the climatic and geographical factors influencing tree growth, as trees in the same region under similar conditions typically exhibit comparable ring patterns reflecting shared climatic influences. Other factors, such as competition and insect activity, can also alter growth patterns. Skeleton plotting visually represents tree-ring widths by graphing narrow rings onto a "skeleton plot" for comparison with master chronologies developed from extensive sampling, enabling precise identification of the year of ring formation (figure 1).

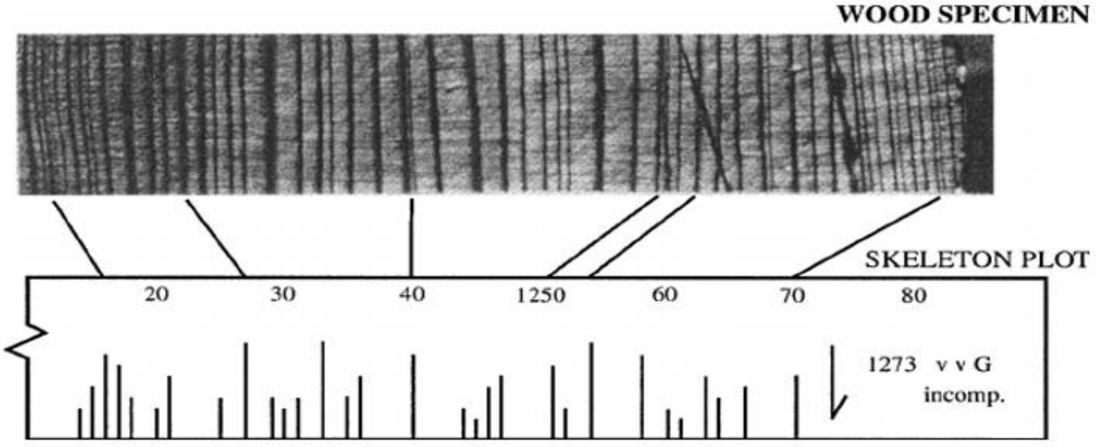

Figure 1. A schematic representation of a skeleton plot, which is a graphic representation of ring-width variability that emphasizes narrow rings and other ring characteristics (Nash, 2002)

Cross-dating with TSAP Win software

Using TSAP-Win software, which combines visual and statistical cross-dating methods, tree ring dating is accurately achieved. Ring-width data is organized into two stacks: the reference stack, containing samples with the most rings, and the working stack, with the remaining samples. Visual cross-dating aligns ring-width patterns graphically, while statistical cross-dating validates matches using the Cross Date Index (CDI), a measure of correlation strength. Each sample in the working stack is compared to the reference stack, with the highest CDI indicating the best match. This process ensures precise chronological sequencing of tree rings for accurate dating.

Cross-dating Parameters

In dendrochronological studies, Gleichlaeufigkeit and the t-value are key concepts utilized to evaluate the quality of conformity between time series. Gleichlaeufigkeit is a specialized tool for cross-dating tree rings, while the t-value is a widely recognized measure for assessing correlation significance (Eckstein & Bauch, 1969). Both concepts emphasize sensitivity to the distinct patterns observed in tree rings. Gleichlaeufigkeit evaluates the agreement between two series, whereas the t-value is particularly responsive to extreme values within the data. The Cross Dating Index (CDI) integrates these two metrics, providing a robust parameter for the cross-dating process. In the output of TSAP-Win software, CDI values are arranged in descending order to prioritize potential matches in the series. This combined approach enhances the reliability of cross-dating by leveraging the complementary strengths of Gleichlaeufigkeit and t-values.

Statistical analysis

Standardization

Standardization is critical in dendroclimatological studies to isolate climatic signals from tree-ring data. This process involves removing non-climatic signals, such as those arising from biological factors or other tree disturbances, by applying appropriate curve-fitting techniques to the tree-ring data series.

This study's raw data series were detrended and standardized using the ARSTAN software, a FORTRAN-based program designed explicitly for dendrochronological analyses. A cubic smoothing spline was applied with a frequency cutoff of 50% and a response threshold of 2/3 the mean series length, ensuring the preservation of high- to medium-frequency climatic variability (Cook & Kairiukstis, 1989). Using autoregressive modelling, the first-order autocorrelation was removed from the detrended series, resulting in a pre-whitened series. These pre-whitened series were averaged using a bi-weight robust mean to construct the final chronology, effectively capturing the climate signal while minimizing noise and non-climatic influences.

Construction of index values

The values derived from applying the cubic smoothing spline technique are referred to as predicted or expected values. These predicted values are instrumental in calculating the Ring Width Index (RWI), which is essential for subsequent reconstruction processes. The resulting index series lacks noise and non-climatic signals, ensuring a robust representation of the climatic influence on tree growth.

The RWI values for 1959–2009 were calculated by dividing the actual tree-ring measurements by the predicted values generated using ARSTAN software and the cubic smoothing spline technique (Stokes & Smiley, 1968). The calculation of the RWI is represented mathematically as shown in Equation 1:

$$\boldsymbol{RI_t = \frac{R_t}{Y_t}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{Eq.\ 1})$$

`Where,

RI_t -Ring width Index value for the year t

R_t -Measured tree-ring width value for the year t

Y_t - Predicted yearly ring width obtained from the smoothing spline for year t

Correlation analysis

The relationship between tree growth and climate was analyzed using high-resolution 0.50 x 0.50 grid climate data from CRU TS V.3.21 over the available period. Correlation analysis was performed between tree growth and monthly seasonal rainfall and temperature using PAST software (Version 4.06). The study spanned a dendroclimatic year of 19 months, starting from June of the previous year to December of the current year. Climate and tree-ring data were input into the software, which correlated monthly temperature and precipitation during these months with ring-width indices. Positive correlations indicated favourable climatic influences on growth, while negative correlations suggested adverse effects. Seasonal relationships between tree growth and climate were assessed by analyzing the correlation of ring-width indices with annual precipitation and temperature from the previous and current years. Seven defined seasons were considered: Seven defined seasons, including the previous southwest monsoon (pJJAS), southwest monsoon (June–September; JJAS), previous northeast monsoon (pON), post-monsoon or northeast monsoon (October–November; ON), summer (March-May; MAM), winter (December–February; DJF), and annual (Ram *et al*., 2008).

Dendroclimatic analysis

Dendroclimatic analyses were performed to evaluate the dendroclimatic potential of the samples for climate reconstruction. This potential refers to the capability of the samples and the site to infer past climate conditions based on the available data.

The reliability of dendroclimatic information was assessed using two key statistical parameters: the Signal-to-Noise Ratio (SNR) and the Expressed Population Signal (EPS). The SNR measures the strength of climatic signals within the chronology. An SNR value >1, as per Wigley *et al*. (1984), indicates sufficient dendroclimatic potential for climate reconstruction. The EPS evaluates the relationship between the index chronology and the sampled population, reflecting the reliability of the chronology and site for climatic studies. Wigley et al. (1984) state that an EPS value ≥0.85 confirms robust dendroclimatic potential. These metrics ensure the suitability of the samples for reconstructing past climate variations.

. The calculations for SNR and EPS were based on established equations (**Eq. 2 and Eq. 3**) designed to quantify the statistical strength and consistency of the dendroclimatic signal.

$$\textbf{Signal to Noise Ratio (SNR)} = \frac{N_t}{(1-r)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\textbf{Eq. 2})$$

$$\textbf{Expressed Population Signal (EPS)} = \frac{N_t}{(N_t + 1 - r)} \ldots\ldots\ldots\ldots (\textbf{Eq. 3})$$

Where,

N – Number of trees/radii
r – Pearson’s correlation coefficient

Result and Discussion

Ring width measurement

The average annual ring width of the samples analyzed in this study was 4.595 mm, based on raw ring-width series spanning 1959 to 2009. The data revealed an age-related growth trend, with relatively larger ring widths during the early growth years (14,168.33 µm) that gradually declined, reaching 2446.67 µm in the final year of growth. This trend underscores the characteristic decline in teak tree ring width with advancing age (Figure 2).

The chronology also exhibited variability due to climatic and non-climatic factors, including tree age, local and regional disturbances, and climatic influences beyond temperature and precipitation. Significant fluctuations were observed, with high ring widths in early growth (during 1959) followed by alternating periods of increase and decrease. A marked reduction in ring width between the initial and final years was particularly evident. These observations align with findings by Brookhouse and Brack (2008), who suggested that site-specific factors and tree age strongly influence tree-ring variability.

Interestingly, the variability in growth rings provides further evidence of the influence of site-specific environmental conditions and underscores the importance of integrating local climatic data for accurate growth modelling. For instance, studies in regions with contrasting rainfall patterns, such as Kerala and Maharashtra, highlight significant disparities in growth trends (Gouri *et al*., 2023). Additionally, the role of seasonal climatic factors in affecting the periodicity and growth of rings supports the need for detailed dendroclimatic reconstructions to inform sustainable forestry practices.

For example, Verheyden *et al*. (2004) noted similar growth patterns in tropical tree species like Rhizophora mucronata, emphasizing the universality of age- and site-related growth variations in dendrochronological studies. Consistent with these studies, the present analysis confirms that younger trees generally exhibit wider rings, and ring width decreases as trees age. The observed age-related growth trend provides valuable insights into the chronology's reliability and the factors influencing teak growth, making it a critical reference for regional forestry and climate research (Gouri *et al*., 2023)

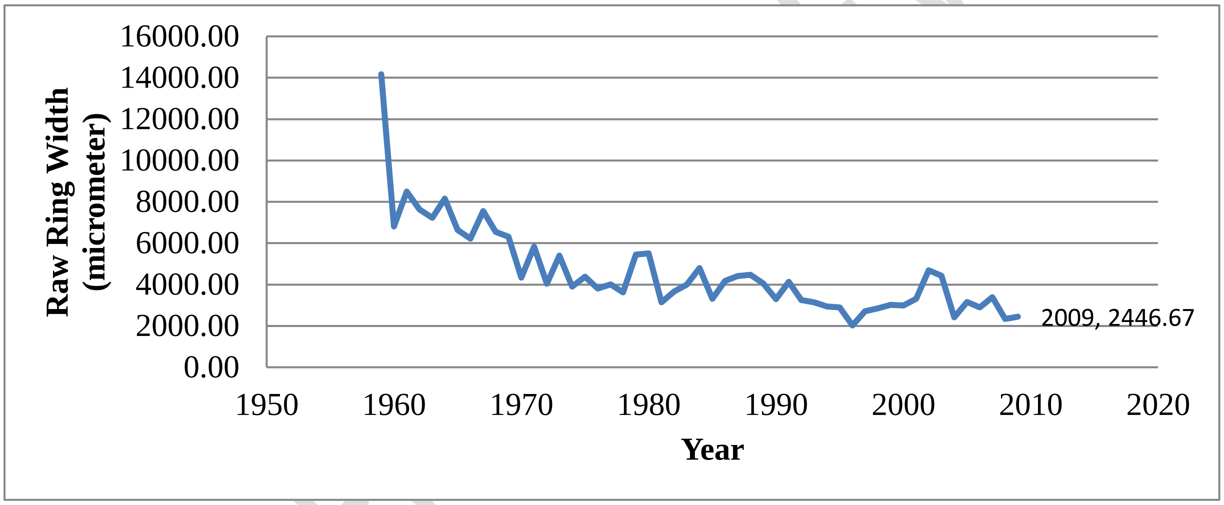

Figure 2. Graphical representation of average raw ring widths measured from 1959 to 2009

Ring width index

The ring-width index values of the study site were analyzed to evaluate the dendroclimatic potential of *Tectona grandis*. This analysis sought a high mean correlation among all radii, reflecting similarities in ring widths and growth trends. The mean correlation, calculated using PAST software, was 0.5855. Ring-width index values were derived by dividing raw ring widths by corresponding smoothed values, ensuring comparability (Figure 3).

Two statistical parameters were used to assess dendroclimatic potential further: Signal-to-Noise Ratio (SNR) and Expressed Population Signal (EPS). An SNR above 1 indicates a reliable chronology, with the study's SNR of 7.24 confirming the strong potential of these samples for reconstructing past climates. The EPS value, a measure of the chronology's representativeness, was 0.878, surpassing the reliability threshold of 0.85 (Wigley *et al*., 1984). Unlike the raw ring-width series, which reflected age-related trends, the standardized chronology (1959–2009) was free of non-climatic influences, ensuring a clearer climatic signal. These findings validate the chronology's reliability for dendroclimatic studies (Table I).

Gouri *et al.*, 2023 corroborate these results, demonstrating robust dendroclimatic potential in teak samples from Nilambur with a slightly higher mean correlation (0.6159), SNR (7.81), and EPS (0.896). The consistency between the SNR and EPS values in both studies underscores the reliability of teak as a dendroclimatic proxy. Similar to this study, Gouri *et al.* used standardization techniques to remove non-climatic influences, affirming the importance of these methods in dendroclimatic research. Both studies highlight rainfall and temperature as key influences on ring-width variability. While this study confirmed a positive correlation with rainfall and a generally negative correlation with temperature, Gouri *et al.* provided additional insights into seasonal patterns, emphasizing the role of monsoonal and post-monsoonal rainfall in enhancing growth. Together, these findings emphasize the broad applicability of teak tree-ring chronologies for reconstructing past climates. The consistent dendroclimatic signals across both studies highlight the teak's resilience to local variability, making it an invaluable resource for understanding historical climate patterns and guiding sustainable forestry practices.

Table I. Statistics of Tree ring Chronology of *Tectona grandis* from the Study Area

Chronology time span	1959-2009
Number of trees	3
Number of radii	9
Mean correlation among all radii	0.5855
SNR	7.24
EPS	0.878

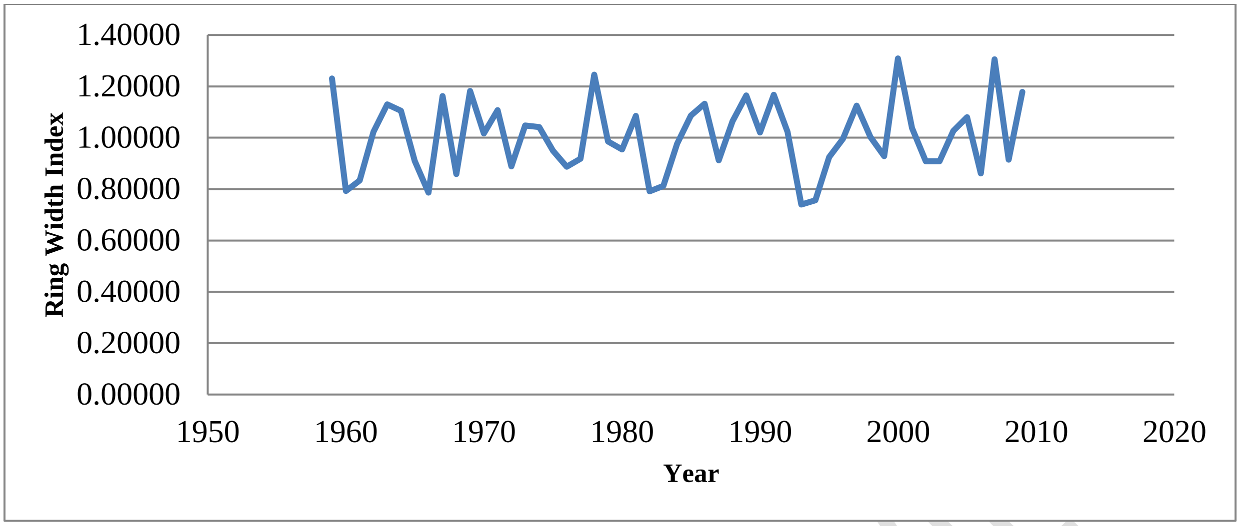

Figure 3. Graphical representation of ring width index calculated for 1959 to 2009 tree rings

Correlation between climate and ring width

Precipitation and ring width

The tree-ring width chronologies from the Thrissur teak plantation sites demonstrated significant correlations with precipitation. Positive correlations were observed with June (0.339), July (0.204), and September (0.37) precipitation of the previous year, indicating that increased moisture during these months promoted wider tree rings (Figure 4). Similarly, current-year precipitation in April (0.293), May (0.33), July (0.376), and September (0.235) also positively influenced growth, emphasizing the role of consistent rainfall. Conversely, negative correlations with January (-0.257) and March (-0.248) precipitation suggest limited growth during these months.

Moisture availability, influenced by rainfall and temperature, is crucial for teak growth. Ram et al. (2008) noted that low rainfall restricts growth, while adequate rainfall enhances it. This study found that low precipitation in March correlated with minimal growth, whereas increased rainfall from June to September supported substantial radial growth. These findings highlight the seasonal nature of teak growth, with peak activity during the monsoon months and reduced activity during drier periods.

The results align with Gouri *et al.*, 2023, which also highlighted the importance of seasonal rainfall, particularly during the monsoon months (e.g., June, July, and August), in promoting growth. Both studies observed consistent positive correlations between precipitation and tree-ring width, underscoring the critical role of moisture availability. The influence of post-monsoon rainfall, observed by Gouri *et al.* for October, complements the findings for September in the Thrissur study, demonstrating a shared pattern across different regions.

Temperature emerged as a moderating factor in both studies. While this analysis showed reduced growth during dry months such as March, Gouri *et al.* similarly observed the adverse effects of high temperatures on growth during pre-monsoon periods. These findings emphasize the interplay between moisture and temperature in determining growth, with optimal growth requiring sufficient rainfall and moderate temperatures. Studies validate teak's sensitivity to climatic variability and its potential as a reliable proxy for dendroclimatic analysis. These insights are vital for understanding growth dynamics and optimizing plantation management strategies under changing climatic conditions.

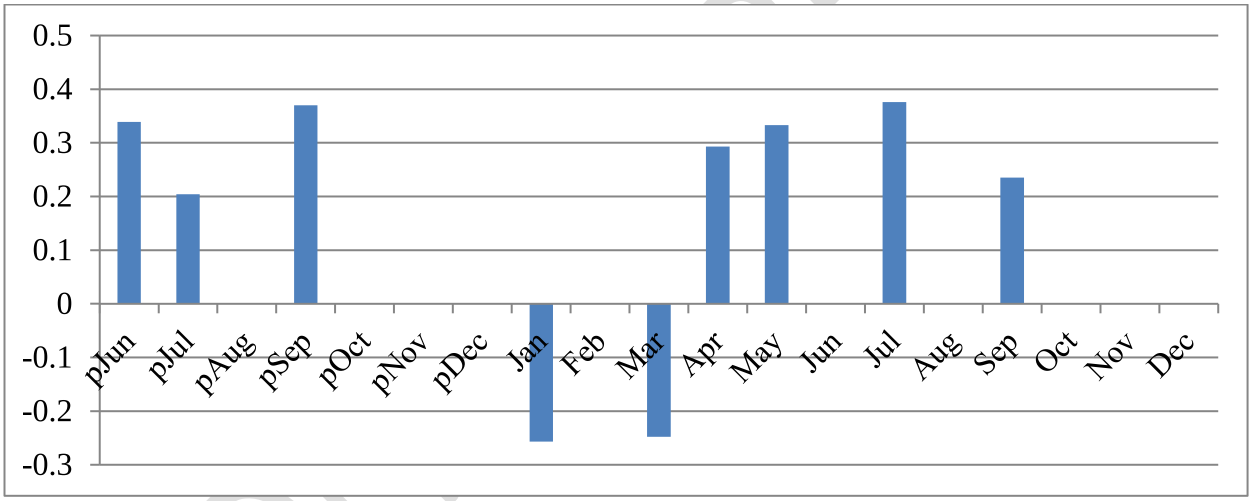

Figure 4. Correlation between precipitation and ring width index chronology

Temperature and ring width

The tree-ring width chronology showed a significant negative correlation with temperature during June (-0.322), July (-0.203), and August (-0.274) of the previous year and June (-0.401) of the current year, indicating that higher temperatures limited growth and narrowed rings. Positive correlations between November of the previous year (0.395) and February of the current year (0.302) suggest favourable conditions during these months, likely due to moisture from earlier precipitation, which supported growth (Figure 5). These findings align with Gouri *et al.*, 2023, which reported similar negative correlations during pre-monsoon periods, such as March (-0.356), April (-0.291), and July (-0.349), highlighting the adverse effects of elevated temperatures on radial growth. Positive correlations with November temperatures (0.332) in Gouri *et al.* further reinforce the role of moderate conditions and adequate moisture in supporting growth.

High pre-monsoon temperatures reduce growth due to moisture scarcity, as Borgaonkar et al. (1996) noted, while increased precipitation during these months significantly enhances early growth. Similarly, Gouri *et al.* observed monsoonal and post-monsoonal rainfall mitigating temperature stress and promoting growth during favourable periods. Sinha *et al*. (2011) emphasized the importance of pre-monsoon showers for initiating cell formation, findings echoed by Gouri *et al.*, who highlighted the positive role of post-monsoonal precipitation in sustaining radial growth. These studies confirm that precipitation consistently supports teak growth, while elevated temperatures often hinder it. These patterns underline teak's sensitivity to seasonal climatic dynamics and its value as a proxy for reconstructing past climatic conditions.

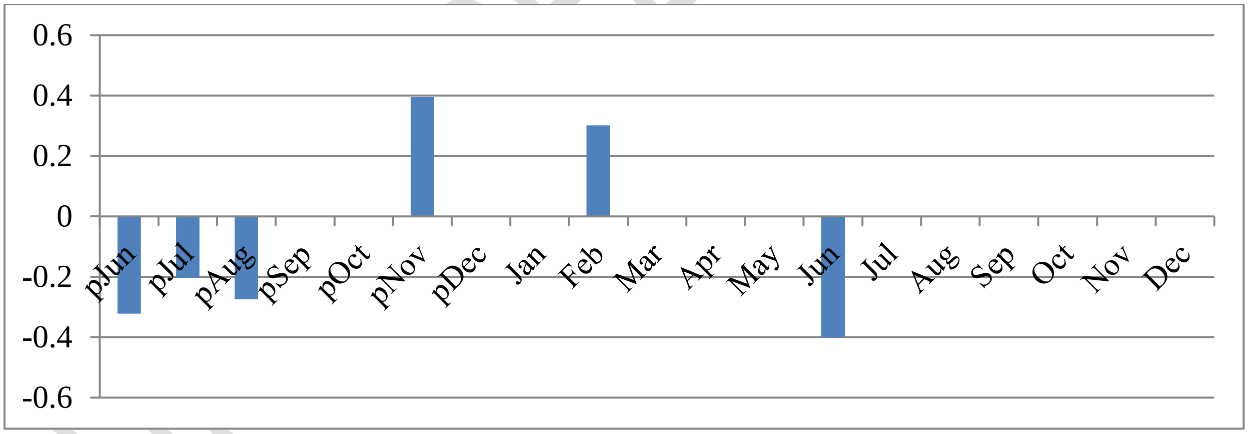

Figure 5. Correlation between temperature and ring width index chronology

Climate and ring width

The correlation analysis between tree-ring width chronology and annual precipitation revealed positive patterns, particularly during the southwest monsoon (JJAS) of the previous year (0.419) and the current year (0.347), as well as the northeast monsoon (pON) of the previous year. Positive correlations with current-year winter (DJF) (0.267) and summer (MAM) (0.227) precipitation also indicate enhanced tree growth during these periods (Figure 6). Conversely, annual temperature showed a significant negative effect on growth during the current year's southwest monsoon (JJAS) (-0.361) and summer (MAM) (-0.346), resulting in narrower rings (Figure 7). However, positive effects were noted during the previous southwest (pJJAS) and northeast monsoons (pON), reflecting favourable moisture availability. These findings align with Gouri *et al.*, 2023, which similarly observed strong positive correlations between growth and precipitation during the southwest monsoon (e.g., July: 0.354, August: 0.385) and post-monsoon (October: 0.355) periods. Gouri *et al.* also highlighted winter precipitation's role in sustaining growth during drier months. Both studies emphasize the significance of seasonal precipitation in promoting teak growth.

The negative impact of temperature on growth aligns with Gouri *et al.*, 2023, which found adverse effects during pre-monsoon months (e.g., March: -0.356, April: -0.291). Elevated temperatures increase moisture stress, suppressing growth during critical periods, while favourable conditions in post-monsoon months (e.g., November: 0.332) can mitigate these effects. Studies like Pumijimnong (2013) and Sinha *et al*. (2019) further validate the interplay between temperature and precipitation. High temperatures and low rainfall reduce growth, while adequate moisture during monsoons and post-monsoons enhances it. This study and Gouri et al., 2023 highlight teak's sensitivity to climatic variability. In conclusion, annual precipitation, especially during monsoon and post-monsoon seasons, is crucial for growth, while elevated temperatures generally hinder it. These findings underscore the importance of managing teak growth with careful consideration of precipitation and temperature patterns.

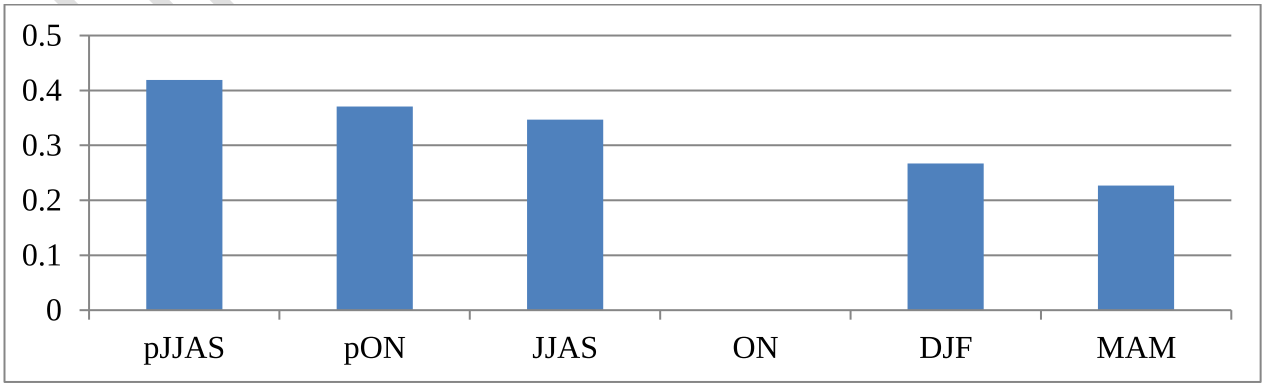

Figure 6. Correlation between annual precipitation and ring width index chronology

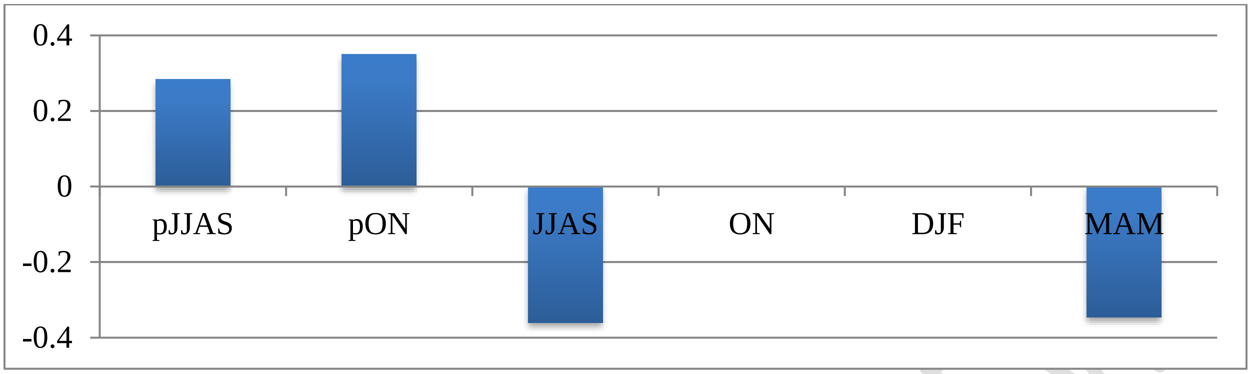

Figure 7. Correlation between annual temperature and ring width index chronology

Conclusion

Teak (*Tectona grandis*) has proven to be an exceptional species for understanding past climates, thanks to its ability to record long-term climatic patterns in its growth rings. By studying these rings, we can uncover valuable information about historical temperature and rainfall, providing insights that stretch back hundreds of years. In this study, the teak samples from Thrissur demonstrated a high signal-to-noise ratio (SNR = 7.24) and expressed population signal (EPS = 0.878), affirming their reliability for reconstructing past climate conditions. These findings highlight teak's potential for scientific research and practical applications in plantation management and timber quality assessment.

Precipitation emerged as the key driver of tree growth, with positive impacts during both the previous and current southwest (JJAS) and northeast (ON) monsoons, as well as during the winter (DJF) and summer (MAM) seasons. This underscores the vital role of moisture in supporting tree growth and ring formation. On the other hand, temperature often posed a challenge, negatively affecting growth during the current year's southwest monsoon and summer. However, during the previous year's monsoon season, the positive influence of favourable climatic conditions prevailed. This interplay between rainfall and temperature paints a detailed picture of how climate shapes the growth of teak trees.

This study's contribution to understanding how teak responds to seasonal climate variability is particularly significant. This knowledge is not just academic—it can guide sustainable forestry practices, help manage plantations in changing climates, and even predict how trees might grow under different climatic scenarios. Expanding this research to include multiple sites in diverse climatic regions would deepen our understanding of regional and global trends. By piecing together a broader picture of monsoon variability and climate-growth relationships, we can better prepare for the challenges a changing climate poses. In essence, this study reinforces the remarkable potential of teak as a natural recorder of climate history, offering scientific and practical insights. It reminds us of the intricate connections between nature and climate and the invaluable stories trees can tell if we take the time to listen.

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