

Development and Application of a Low-Cost CT Prototype for Analyzing Growth Ring Formation

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Abstract

This study explores the potential use of a Computed Tomography (CT) imaging system for analyzing the internal structure of tropical wood, specifically the *Angsana* tree (*Pterocarpus indicus*). The main challenges are developing an efficient and affordable CT system, proving that the CT system can observe tree rings, and relating the tree rings to the past climate conditions in the region where the tree is grown. We have developed a CT system using a fluoroscopic x-ray power of 170–240 keV, 5mA. We have collected 360 multiple radiographs with a resolution of 2448 × 2048 (5MP) for a field of view of 100 mm × 65 mm. The CT image reconstruction method uses the summation convolved filtered back-projection (SCSCFBP) method. We have tested the CT system for tree rings of the *Angsana* tree branch sample of 30 mm diameter and 130 mm length. It grows in tropical regions, e.g., the Bantul regency in a Special Region of Yogyakarta, Indonesia. The results showed that the CT images from our system could identify growth rings and deformations within the wood. Analysis revealed the presence of five growth rings in the samples, which correlated with annual precipitation data in the Bantul region, in which significant growth occurred in years with higher precipitation. The system and its method demonstrate its potential application in dendrochronological analysis in tropical regions, providing critical information about past climatic conditions without damaging the trees. This affordable CT system can be used for environmental conservation, and climate change applications.

Introduction

Advancements in X-ray imaging technology have opened new opportunities in forest engineering, particularly for non-destructive analysis of internal wood structures to support forest management, wood quality assessment, and sustainable harvesting planning. Among these technologies, computed tomography (CT) scanning stands out for its ability to produce three-dimensional (3D) visualizations of wood anatomy without compromising sample integrity. This method enables precise observation of growth rings, wood density variations, and internal features such as heartwood and sapwood, which are critical for evaluating growth performance and site productivity [1–4]. CT scanning has been applied in various studies to support decisions in wood procurement and silvicultural practices by providing insights into tree development and environmental interactions [5,6]. Due to its ability to generate detailed imaging without causing damage, this method has the potential to enhance the accuracy of observing tree growth [3, 7, 8].

CT scanning has been applied in various studies to support decisions in wood procurement and silvicultural practices by providing insights into tree development and environmental interactions [1, 5, 9]. Conventional methods for analyzing tree growth rings also present numerous challenges. One major challenge is the difficulty in observing growth rings in tropical regions, where ring boundaries are often indistinct and difficult to identify visually [10, 11]. Several non-destructive methods, such as visual inspection and ultrasonic testing, have been developed, but these methods have limitations in detecting internal wood conditions that are not directly visible [12–14].

To overcome these challenges and promote broader use of internal wood analysis in forest engineering, this study introduces a cost-effective, prototype CT scanning system developed by the Image Physics Study Group at Universitas Gadjah Mada, Indonesia. Designed with affordability and functionality in mind, the system integrates a conventional X-ray machine, CMOS camera-based fluorescence detector, rotational stage, and user-operated control panel. The image reconstruction is carried out using the Summation Convolved Shifted-Filtered Back Projection (SCSCFBP) algorithm.

In this study, the developed CT scanning system was tested to identify growth rings in the branches of Angsana wood (*Pterocarpus indicus*). The samples were collected from Bantul Regency, Special Region of Yogyakarta. Growth ring identification was conducted to understand tree growth patterns and how environmental factors influence this process. We used rainfall data from the Meteorology, Climatology, and Geophysics Agency (BMKG) of Yogyakarta Province over the last ten years to investigate the relationship between growth patterns and environmental conditions [15, 16].

Materials and Methods

Sampel and Taxonomy Concept

The samples used in this study consisted of two wood branch segments from the Angsana tree, a tropical tree commonly planted along roadsides as a pollution absorber (air and noise). *Angsana* is a type of tree that produces redwood. This tree comes from several tropical countries, such as Malaysia, Papua New Guinea, the Philippines, Cambodia, Thailand, Vietnam, East Timor, the Solomon Islands, and Indonesia [17]. Natural populations of *P. indicus* in Indonesia are spread across the islands of Sumatra, Java, Kalimantan, Sulawesi, Maluku, and Lesser Sunda [17, 18]. The Angsana tree is part of the family *Fabaceae*, which includes the genus *Pterocarpus* and the species *Pterocarpus indicus* [19]. We treated the two wood branches differently in this study. We left the first branch intact to observe the tree rings and used an electric drill to drill a hole in the inner part of the second branch. The selected wood branches did not display tree rings. The wood branches used were 30 mm in diameter and 130 mm in length. We used tree branches in this study to investigate past climate shifts, avoiding the risk of damaging the tree's main trunk by cutting it down.

Site Description

We conducted this study to analyze the relationship between tree ring growth and climate change data [20, 21, 22] in tropical regions of Yogyakarta, Indonesia, using computed tomography imaging methods [6, 23]. We collected the samples for this study from the Bantul district in Yogyakarta province, Indonesia. Bantul Regency is in the southern part of Yogyakarta Province's Special Region. Geographically, Bantul Regency is situated at East Longitude 110° 12' 34" to 110° 31' 08" and South Latitude 7° 44' 4" to 8° 00' 27" [24–26]. The Bantul district experiences an average annual rainfall of 90.76 mm, with the highest in December, January, and February [27]. The average air temperature in

Bantul remains relatively consistent throughout the year, at approximately 30⁰ Celsius. Topographically, the Bantul district predominantly comprises 40% lowlands and 60% less fertile hilly areas [28, 29]. The administrative map of the Bantul district, Yogyakarta, is shown in Fig. 2 below. The map shows the locations where we collected the samples of Angsana tree branches for this study. Figures 3 and 4 below display the graphs showing the precipitation levels in Bantul Regency, Yogyakarta. This data is obtained from the Meteorology, Climatology, and Geophysics Agency of Yogyakarta's Website, covering the past ten years, from 2015 to 2024.

Experimental Design

The image physics study group at Universitas Gadjah Mada in Indonesia designed the industrial CT technology for this study, as shown in Fig. 5. The CT system comprises four main components: an X-ray source, a detector, a gantry (rotational stage), and a control panel. Lead-lined (Pb) walls surround these four components, protecting against X-ray radiation hazards during operation. The x-ray machine is from Dandong Zhongyi Electronic of China. This X-ray tube has the specifications of a ceramic tube directional moaAsxzdel, XXG-2505 flaw detector, operating at a current of 5 mA and output voltage 130–250 kV. The multiple radiography images were collected based on absorptive fluoroscopic images captured by a CMOS camera with a frame rate of 3 fps (frames per second). At the same time, the branch tree sample was rotated on the rotating stage. Each radiography image has a resolution of 2448 × 2048 (5 megapixels) to record a field of view (FOV) of 100 mm × 65 mm. The rotation speed used is 0.2745 rpm, allowing the acquisition of 436 projections during a full 360° scan, with a total exposure time of 228 seconds for all projections. The CT image reconstruction employed a summation convolved filtered back projection (SCSCFBP) method.

Image Reconstruction

This study employs the Summation Convolved Filtered Back Projection (SCSCFBP) method to reconstruct 3D cross-sectional images of Angsana tree branches, based on filtering, back projection, and summation [30]. Initially, projected images are converted into 2D sinogram representations of projection data collected from various angles. Each projection angle has a center of mass (CoM), calculated using the X-ray attenuation coefficient, ensuring reconstruction accuracy. After CoM correction, filtering minimizes artifacts in the back projection process. A 1D Fourier transform is applied to each projection in the sinogram [31], converting data between spatial and frequency domains. A high-pass filter, commonly the Ram-Lak filter, enhances high frequencies while reducing low ones [32, 33]. The inverse Fourier transform then returns the data to the spatial domain [34]. Finally, filtered projections are back-projected and stacked to form a 3D matrix, where each element has an intensity value, constructing the final 3D volume.

Data Analysis

This study analyzed the reconstructed images using the plot profile method to determine the number of tree rings formed in the branches of the Angsana tree. Each peak in the graph was counted as a ring pattern, providing a quantitative representation of growth cycles. The ring patterns were then reconstructed in the 3D images of the Angsana tree branches based on the number of rings identified through plot profile analysis. Furthermore, the study investigated the relationship between ring growth width and annual precipitation levels in the Bantul district, Yogyakarta. We plotted the measured ring widths as a graph using Origin software to analyze growth patterns with yearly rainfall variations.

Results

The identification of Angsana tree branch sample characteristics in this study aimed to evaluate the capability of the simple CT scan prototype we developed in detecting growth rings in wooden branches. The identification of rings was conducted through image reconstruction using the Filtered Back Projection (SCFBP) method with a slice thickness of 100 slices derived from the 2D projection images obtained after the scanning process. Figure 6(a) displays the 2D projection image of the samples from the Angsana tree branch, where the branch was placed inside a pipe. To ensure stability during the scanning process, a paper wedge was placed at the top of the object to keep it in a fixed position. In this study, the object projections generated 2D images with a resolution of 2448×2048 pixels. These images were then segmented with a specified pixel thickness, as shown in Fig. 6(b), to facilitate 3D reconstruction of the object. This segmentation was performed to selectively examine specific regions of interest and enhance the efficiency of the reconstruction process.

Figure 7 displays the reconstructed CT images of the wood from an Angsana tree branch. The reconstructed images have a resolution of 2448×2448 pixels. Figure 7(a) shows the cross-sectional view of the branch while still enclosed within the pipe. Meanwhile, Fig. 7(b) provides a more detailed visualization of the internal structure of the branch, revealing key components such as the outer bark layer, the center of the rings, and the growth rings. However, not all growth rings in the Angsana tree branch are identifiable in the reconstructed images, with only a portion being distinctly visible. The width of the tree rings varies significantly, and the cross-section of the outermost wood layer is distinguishable. By analyzing these tree ring characteristics, valuable insights into the tree's age and past environmental conditions can be obtained. Figures 7(c) and (d) present the 3D reconstruction results of the Angsana tree branch, showing cross-sectional views along the x and y axes. The identification of growth rings in the Angsana branch reveals alternating light and dark patterns, which reflect the climatic conditions experienced by the tree throughout its lifespan. To accurately determine the number of visible rings in the branch image, a plot profile analysis is conducted. A straight line is drawn from the center of the ring of the Angsana tree branch towards the bark and analyzed using the plot profile method.

The plot profile analysis is based on the gray-level intensity at each tree ring; high gray-level intensities indicate ring boundaries in the cross-sectional image of the Angsana wood. Consequently, each peak in the graph represents one tree ring. Before conducting the plot profile analysis, a scale factor calibration is performed, establishing that each pixel in the image corresponds to a length of 0.02655 mm. This

value means that 1 mm of actual length is represented by 37.67 pixels in the image. We derive this calibration value from the image resolution from the detector's point of view. Figure 8 below illustrates the plot profile graph of the Angsana tree branch ring image.

Based on the plot profile graph analysis in Fig. 8, at least five peaks are observed, indicating five boundaries of tree ring circles in the cross-sectional image of the Angsana tree branch wood. After determining the number of growth rings, we divided the reconstructed image into ten sections, each with a thickness of 10 slices, as shown in Fig. 9. The primary objective of this segmentation is to accurately measure the average growth ring width in the Angsana tree branch.

The results of the reconstructed image segmentation are presented in Fig. 10. Each section's growth rings are charted using yellow circular markers. In this study, the tree ring count was conducted from the inner part toward the outermost section of the wood, excluding the central core. This approach follows the natural growth sequence, where the oldest rings are located at the center, while the youngest rings are found at the outermost part, just beneath the bark [35–38]. This growth pattern occurs due to the activity of the cambium, a meristematic tissue layer situated between the xylem and phloem in the outer section of the stem or branch. The cambium produces secondary xylem inward, forming annual growth rings, and secondary phloem outward [39–41].

Based on the reconstructed tree ring data from Fig. 10, variations in the width of the growth rings are evident. The average growth ring width measurements presented in Table 1 indicate that the Angsana tree rings in 2019, 2022, and 2023 were wider compared to those in 2020 and 2021. A more in-depth analysis is required to determine the factors contributing to these differences in tree ring growth on the Angsana branch. As previously discussed, several key environmental factors such as regional precipitation levels, temperature, and humidity play a crucial role in influencing tree ring formation [15, 42, 43].

Table 1
Measurement Results of Angsana Tree Growth Rings.

Years	Width of Growth Rings (mm)										Average (mm)
	1	2	3	4	5	6	7	8	9	10	
2019	3.21	3.21	3.20	3.31	3.29	3.18	3.16	3.16	3.03	3.30	3.20 ± 0.08
2020	0.96	1.01	0.96	0.96	0.97	0.98	1.07	0.95	1.06	0.96	0.99 ± 0.04
2021	0.90	0.99	0.97	1.06	0.97	1.07	1.06	0.99	1.01	1.07	1.01 ± 0.06
2022	1.79	1.75	1.75	1.64	1.70	1.79	1.64	1.73	1.87	1.81	1.75 ± 0.07
2023	1.30	1.22	1.22	1.33	1.35	1.24	1.23	1.28	1.17	1.40	1.27 ± 0.07

Based on the data obtained in Table 1, the measurement of growth ring width in Angsana tree branches from 2019 to 2023 exhibited significant variations in annual growth patterns. In 2019, the average growth

ring width reached 3.20 ± 0.08 mm, the highest value recorded during the study period, indicating more optimal growth conditions, likely influenced by water availability, nutrient supply, and favorable temperatures. However, a sharp decline was observed in 2020 and 2021, with average widths of 0.99 ± 0.04 mm and 1.01 ± 0.06 mm, respectively, suggesting the presence of limiting factors such as drought, environmental stress, or resource depletion affecting tree growth. Beginning in 2022, a recovery trend was noted, with an average growth ring width of 1.75 ± 0.07 mm, followed by a slight decline in 2023 to 1.27 ± 0.07 mm, which may have resulted from improved environmental conditions or physiological adaptation of the tree to climatic changes.

Since the temperature in Bantul Regency remains relatively constant at an average of 30°C throughout the year, we investigated the relationship between the average annual rainfall in Bantul Regency and the growth width of *Pterocarpus indicus* tree branch rings. The correlation between tree ring width growth and average annual rainfall is presented in the graph shown in Fig. 11. This graph reveals a distinct growth pattern in the tree rings, which broadly follows the intensity of annual rainfall in Bantul, Yogyakarta.

Figure 11 shows the relationship between annual precipitation and the width of *Pterocarpus indicus* tree branch rings over the study period. The graph indicates that tree ring width generally follows the fluctuations in precipitation, with wider rings observed during years of higher rainfall and narrower rings during drier periods. A significant decline in both variables occurred in certain years, followed by a recovery trend before decreasing again. These findings suggest that precipitation is a key factor influencing tree growth patterns in Bantul Regency, where temperature remains relatively stable throughout the year.

Discussion

4.1 Image Reconstruction

Using the under-development CT system, we obtained 436 image projections for a full 360-degree rotation with a rotation motor speed of 0.2745 rpm for 228 secs. The data acquisition method relies on the camera's frame rates in capturing image projections during the sample scanning process rather than the formal angular step. The image projections underwent an inversion process before the 3D CT image reconstruction process. This image inversion aims to enhance the contrast in the areas of interest. The inversion process will make the dark areas of the image brighter and vice versa. After the inversion, a model fitting process was applied to all projection images to obtain precise total images in a complete rotation. The model fitting method uses the Centre of Intensity (COI) principle to avoid overlapping radiography images (image projection). Therefore, the likelihood of excess image projections is high. The red fitting model line in Fig. 12 follows the COI wave line shown in blue by adjusting the frequency, phase difference, and amplitude. The x -axis of the COI graph represents the total number of image projections, while the y -axis represents the intensity level of the image projections. Figure 12 below displays the outcome of the image projection model fitting of $Y = 44 \sin(0.0153\theta + 5.8) + 1230$.

Based on the COI process, we refined the initial 436 projection images to 411 images by discarding 25 radiographs to suit the formal requirement of the CT image reconstruction. The selected 411 image projections were reconstructed using the filter-back projection (SCFBP) method with a slice thickness of 100 slices. This process produced a 3D image of the cross-section of the *Angsana* tree wood branch. These images were then used to identify the tree rings of the wood structure described in the next section.

4.2 Growth Ring Characteristics

This study utilized X-ray tomography imaging to analyze the growth characteristics of tree rings in the *Angsana* tree branch. Figure 7 presents the 3D reconstruction results of the wood from the *Angsana* tree branch using tomography imaging. Specifically, Fig. 7(a) displays the internal structure of a cross-section of the wood, while Fig. 7(b) visually identifies several internal components, including the central tree ring circle, multiple tree ring lines, and the outer bark layer. However, despite the system's ability to reveal these internal structures, the reconstructed CT images still exhibit several limitations, particularly in the clarity of the growth ring boundaries. Some rings appear blurred due to artifacts and noise introduced during the reconstruction process, making their identification less precise. These imperfections stem from both the limitations of the image reconstruction algorithm and the prototype CT system used in this study.

Based on Fig. 7(b), the tree rings exhibit alternating dark and light patterns, which reflect environmental conditions, particularly ecological factors. In tropical regions, the dark rings correspond to periods of rapid growth during the rainy season, where abundant water availability promotes active cell division and denser wood formation. In contrast, the light rings represent slower growth during the dry season, when limited water availability results in reduced cell production and less dense wood. This seasonal pattern highlights the influence of precipitation on the growth dynamics of the *Angsana* tree. However, the visibility of these growth rings in the CT images is not entirely clear due to the presence of reconstruction artifacts, such as streaking and noise, which obscure the finer details of the ring structure.

This study used the plot profile method to accurately determine the number of tree rings formed using tomography images. The plot profile method is based on the intensity values of the dark and light patterns produced by the growth of tree rings in *Angsana* tree wood. In this study, the light patterns in the images are boundaries between each tree ring circle. Figure 8 presents the plot profile of the wood rings as a graph containing the results. The graph displays at least five peaks that serve as boundaries between each tree ring circle in the plot profile. The information about the number of tree rings obtained was then used to map the location of the tree rings in the tomography images, following the visual boundaries present in the images. Figure 10 displays the mapped results of the tree rings, depicting five circular lines that correspond to the tree rings. The mapping results of the growth ring circles reveal variations in the width of these wood rings. Each growth ring width on the branch provides valuable information about weather conditions throughout its life. This study presents statistical climate change

data on precipitation from Bantul Regency, Yogyakarta Province, to understand the relationship between precipitation and the growth rings on the branch. Figures 3 and 4 show the precipitation data through graphs and bar diagrams.

Figure 3 displays statistical graphs of average precipitation in the Bantul region for each month over the past ten years (2015–2024), while Fig. 4 presents bar diagrams of average annual precipitation over the same period. The data indicate that the lowest precipitation intensity occurs from May to September, whereas the highest levels are recorded at the beginning (January–April) and end of the year (October–December). Annual precipitation statistics further reveal that 2020 and 2021 experienced the lowest precipitation intensities, suggesting prolonged dry seasons, while 2022 and 2024 had the highest rainfall levels.

This variation in precipitation patterns is reflected in the growth dynamics of the Angsana tree (*Pterocarpus indicus*), as illustrated in Fig. 11. In 2020 and 2021, the growth width of tree rings was minimal, corresponding to periods of extremely low precipitation, as evidenced by the visibly narrow rings. In contrast, significant ring growth was observed in 2019 and 2023, characterized by wider rings. A comparative analysis of these variations in ring width with statistical precipitation data from the Bantul region reveals a positive correlation between precipitation and tree ring growth. Notably, in 2019, high precipitation (232.9 mm/year) corresponded to a wider ring formation (3.20 ± 0.08 mm), whereas extremely low rainfall in 2020 and 2021 (6.4–6.9 mm/year) resulted in significantly narrower rings (0.99 ± 0.04 mm and 1.01 ± 0.06 mm), highlighting the critical role of water availability in secondary xylem development. The increase in precipitation in 2022 was accompanied by a corresponding expansion in ring width, reinforcing the influence of water availability on wood formation. However, in 2023, despite a decrease in rainfall, the ring width did not decline substantially, suggesting the presence of additional contributing factors such as groundwater reserves or physiological adaptations that sustained tree growth. These findings indicate that while precipitation serves as a primary determinant of annual tree growth, other environmental factors may also influence tree ring formation and variability.

Previous studies show that precipitation is the primary climatic factor influencing tree-ring growth patterns. During summer periods with low rainfall intensity, the width of tree ring growth can decrease dramatically. Conversely, during periods with higher rainfall intensity, the width of tree ring growth increases significantly unhindered [15, 44, 45]. In 2021 and 2020, the Bantul region experienced a prolonged dry season, which inhibited tree ring growth due to insufficient water supply reaching the tree trunk and branches. Consequently, the growth width of tree ring circles during these years could have been broader and more significant. Conversely, in 2019, 2022, and 2024, Bantul experienced high precipitation intensity. These events directly contributed to optimal growth conditions for the Angsana tree (*Pterocarpus indicus*), as adequate water availability supported their growth. Therefore, the tree ring growth produced during these years was wider. This observation shows that climate change significantly affects tree ring growth. However, the growth of tree rings is not solely influenced by precipitation; other factors such as temperature, humidity, and soil nutrient levels also require further analysis in future study.

Conclusion

This study successfully developed a Computed Tomography (CT) imaging system to analyze the internal structure of *Pterocarpus indicus* tree branches. The reconstructed CT images revealed the presence of five growth rings, which correlated with annual rainfall data in Bantul, Yogyakarta. Ring growth was more pronounced in years with higher precipitation, whereas narrower rings formed during drier years. However, the obtained CT images require further refinement, particularly in enhancing the clarity of growth ring boundaries. Some rings were not distinctly identifiable due to image resolution limitations and reconstruction artifacts. Therefore, further research is needed to optimize scanning parameters and reconstruction algorithms to improve the accuracy of growth ring identification and its correlation with rainfall patterns.

Declarations

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Author Contribution

N.L.S.M. conceived and designed the study, performed CT data acquisition, conducted image processing and analysis, prepared visualizations, and drafted the initial manuscript. I.Z.T.D. contributed to sample collection, experimental setup, and procedural documentation. D.R. engineered and integrated the low-cost CT prototype, ensuring hardware–software functionality. C.M.M. executed advanced image reconstruction and optimized the SCSCFBP algorithm. W.M.D. managed climatological data acquisition, performed rainfall–growth correlation analyses, and interpreted environmental influences on tree-ring formation. R.R. curated the literature review, refined methodological descriptions, and provided substantive manuscript edits. G.B.S. supervised the entire project, validated results, and oversaw critical revisions to produce the final version of the manuscript.

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Data Availability

The datasets generated and analyzed during the current study, including CT projection images, reconstructed 3D volumes, and tree ring measurement data, are available from the corresponding author upon reasonable request.

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Figures

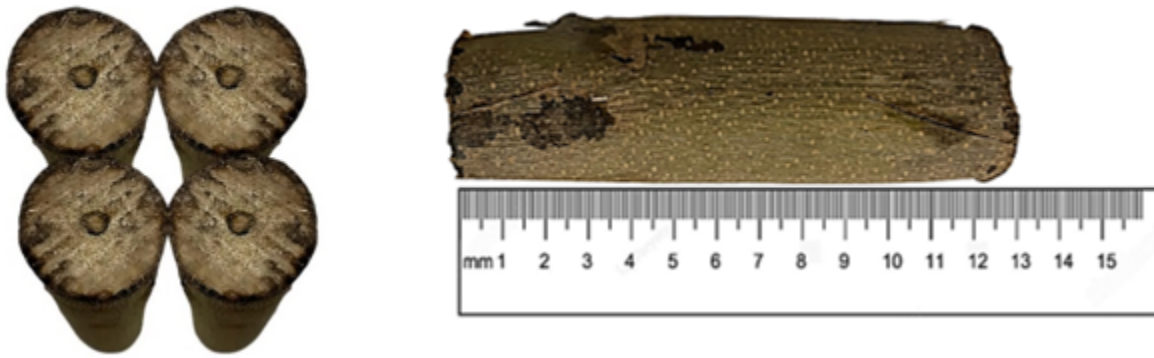


Figure 1

As seen from a top-down cross-section, A wood sample does not visually exhibit tree rings.

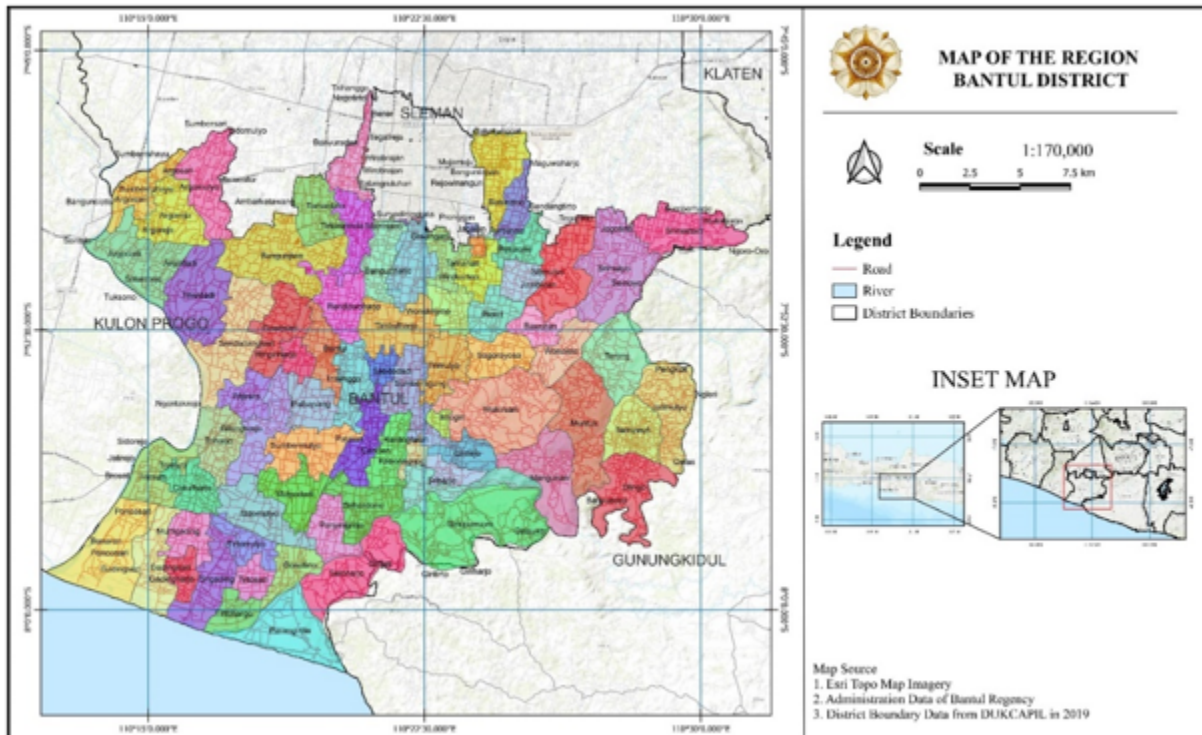


Figure 2

Administrative map of the Bantul district, Yogyakarta. The red circle on the map indicates the sampling location in the Imogiri sub-district, Bantul district.

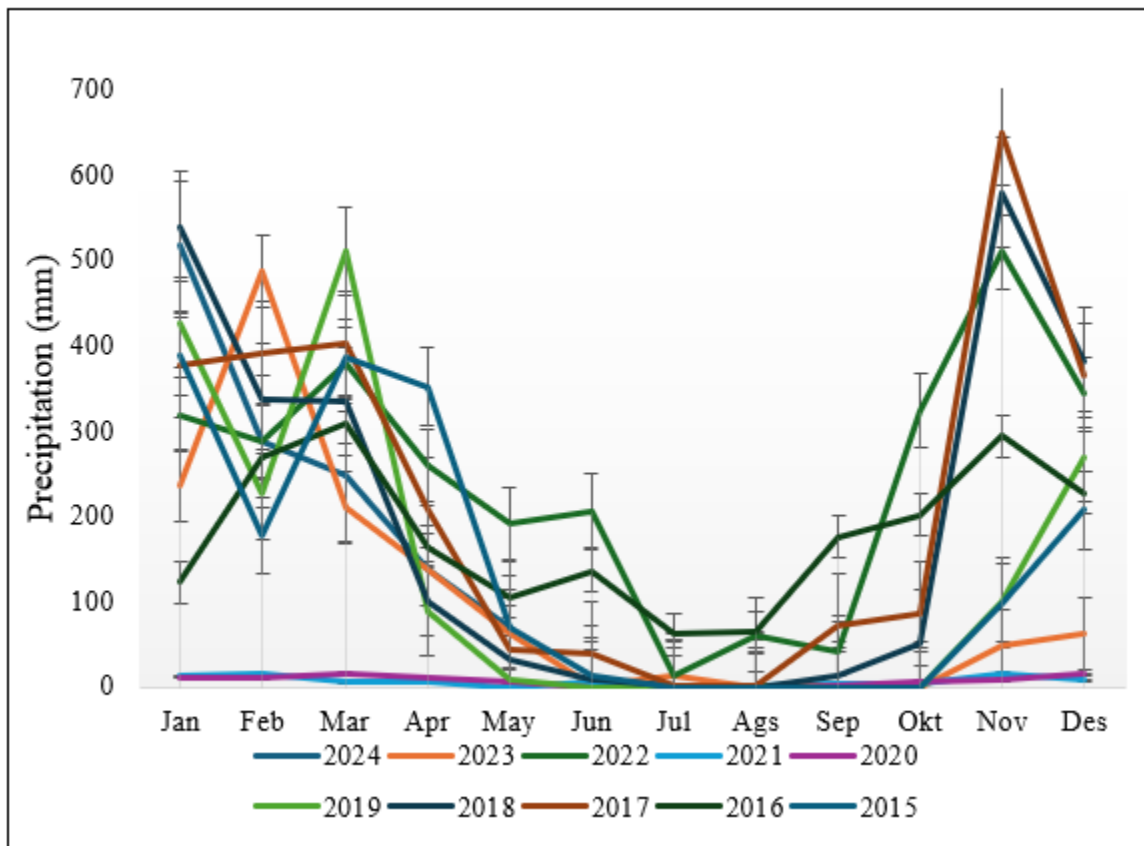


Figure 3

Graph showing the monthly precipitation levels in Bantul Regency from 2015 to 2024. From May to August, the middle of the year consistently sees the lowest precipitation levels in Bantul Regency. Meanwhile, the highest precipitation levels consistently occur at the beginning and end of the year.

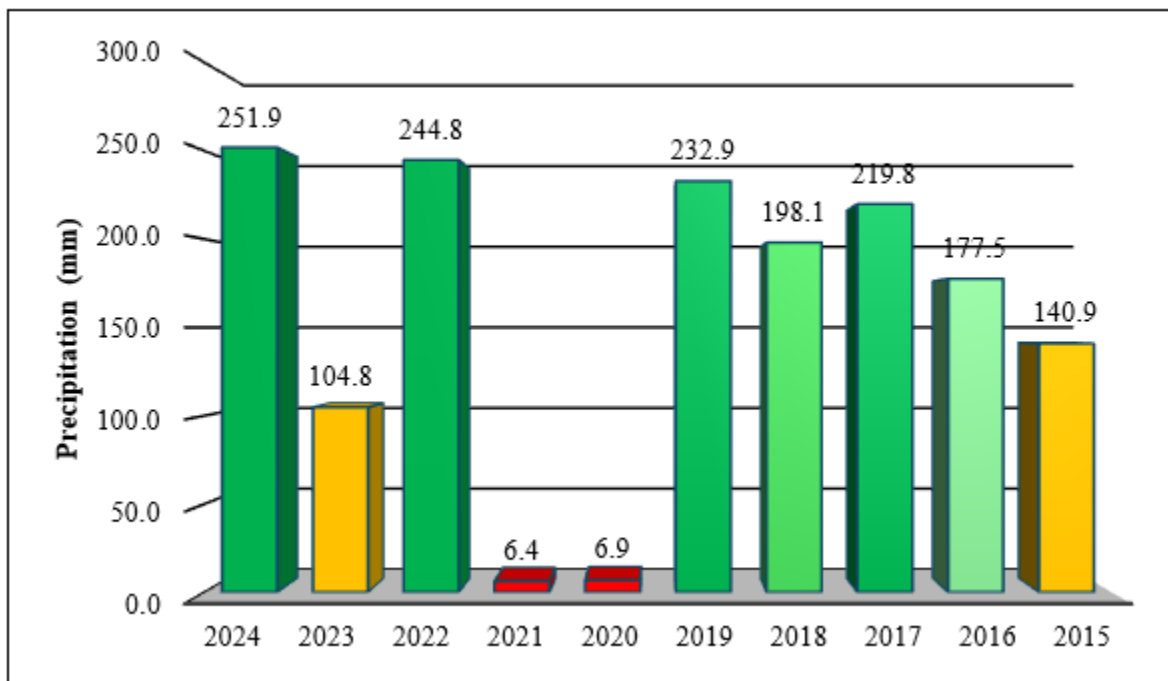


Figure 4

Diagram showing the average annual precipitation in Bantul Regency, Yogyakarta, from 2015 to 2024. The diagram indicates that the highest precipitation in the past ten years in Bantul Regency occurred in 2019, 2022, and 2024. Meanwhile, the lowest precipitation occurred between 2020 and 2021, indicating a prolonged dry season.

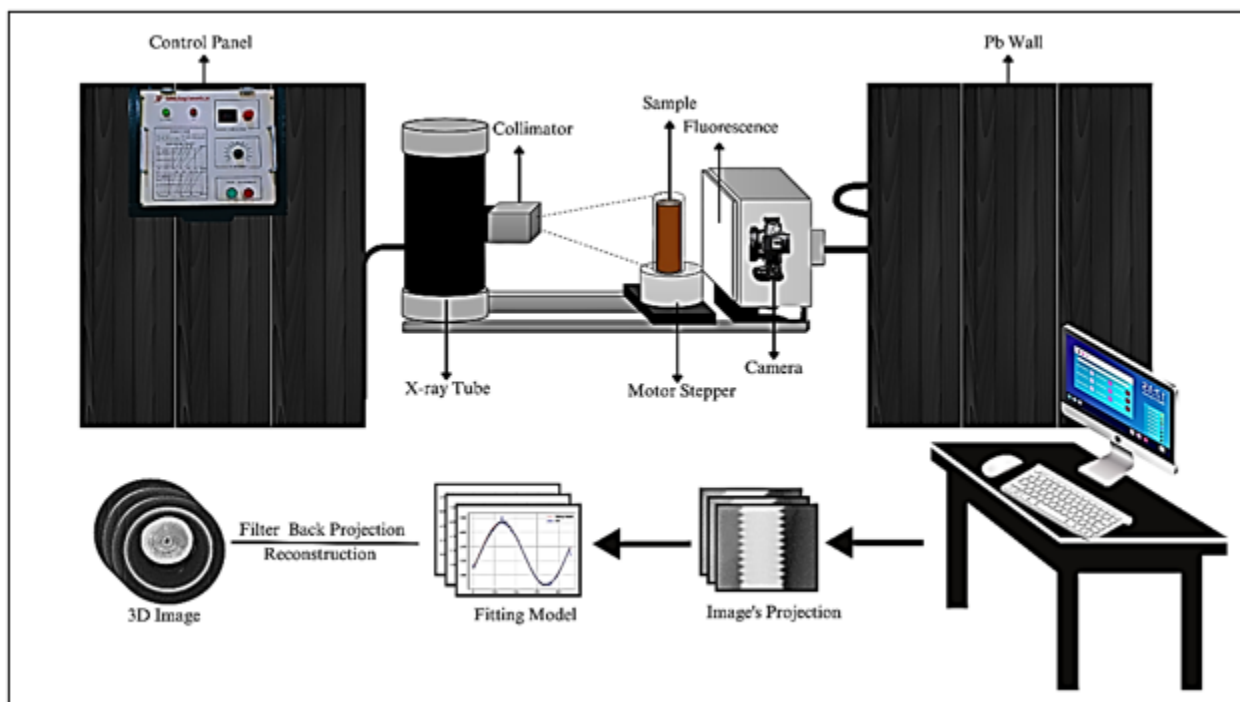


Figure 5

Schematic of industrial CT system at the Department of Physics, Universitas Gadjah Mada. The CT components consist of an X-ray tube, stepper motor, detector comprising a fluorescent screen, and camera, and the projection image results are reconstructed using the SCFBP method.

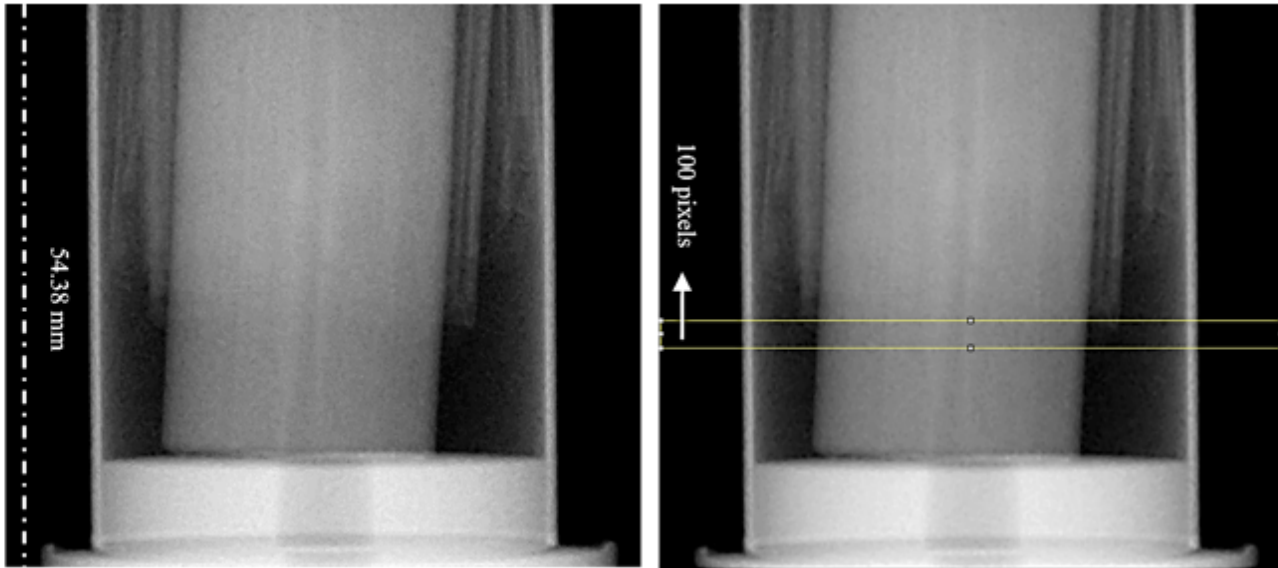


Figure 6

(a) 2D projection image of the Angsana tree branch samples, (b) Image segmentation process for 3D image reconstruction.

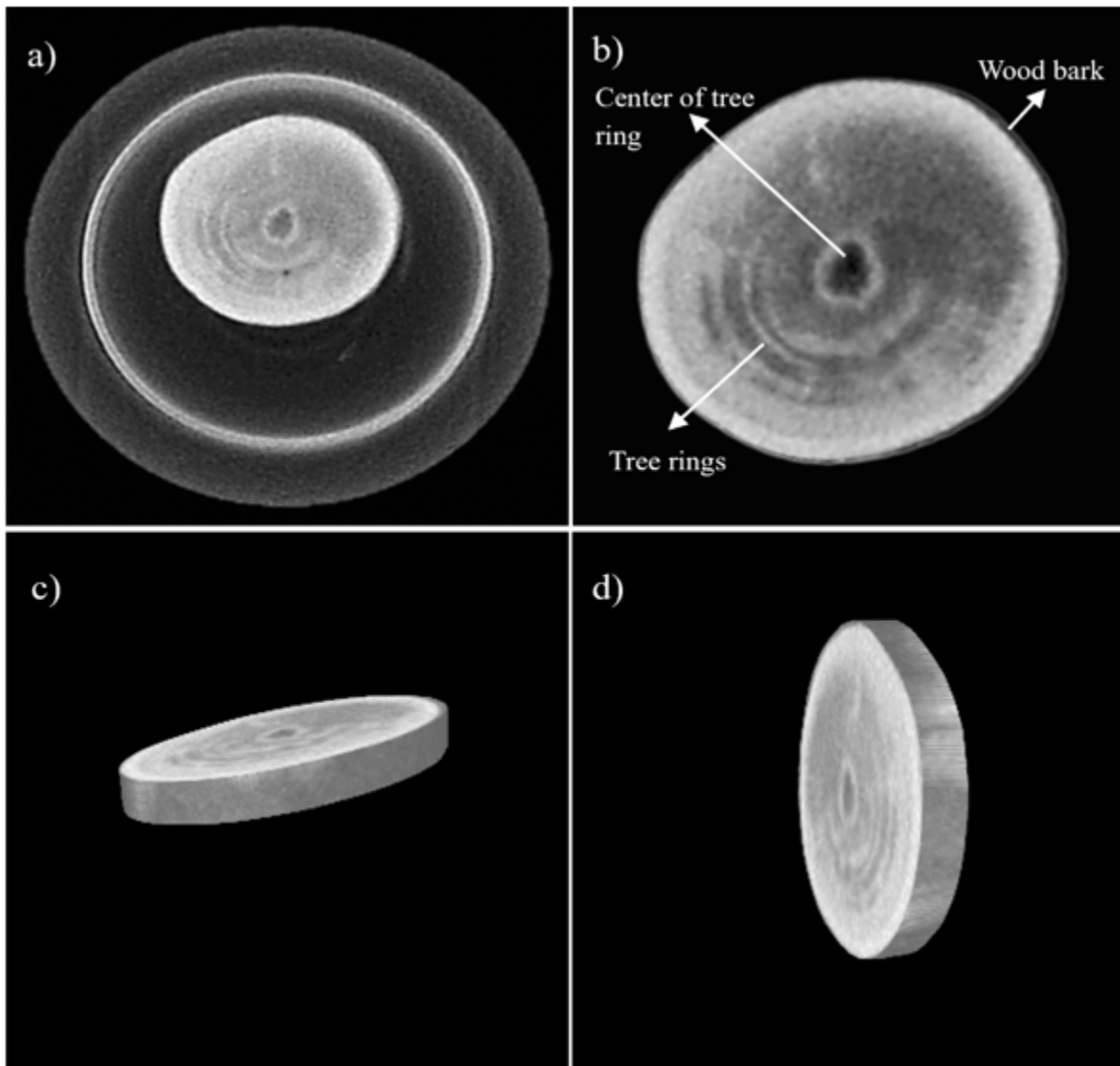


Figure 7

A 3D reconstructed image of the cross-sectional view of an Angsana tree branch. a) The original image shows the cross-section of the Angsana tree branch within a cylindrical pipe before image processing. b) After image processing, a cross-sectional image of the Angsana tree branch demonstrates that the CT image can display the wood bark, tree rings, and the center of the tree rings. c) 3D reconstructed cross-sectional view along the xz axis. d) 3D reconstructed cross-sectional view along the yz axis.

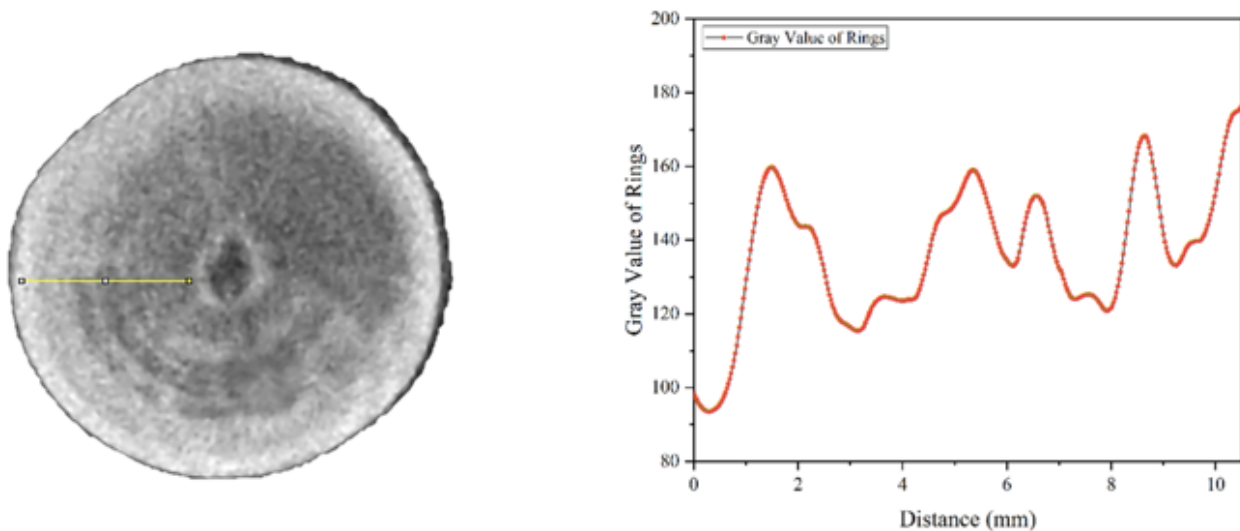


Figure 8

Plot profile graph of the cross-sectional image of tree rings from an *Angsana* tree branch wood. The graph shows several peaks indicating by the numbers of each tree ring in the cross-section of the *Angsanatree* branch wood.

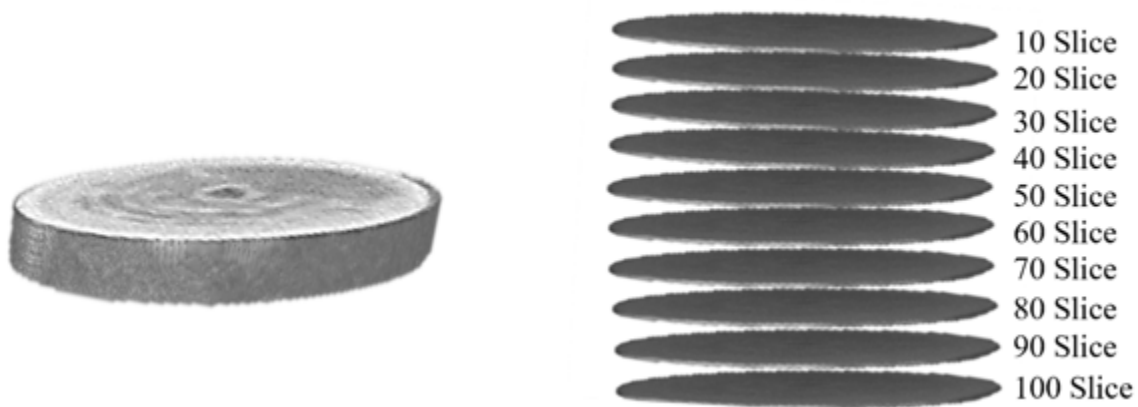


Figure 9

The model for dividing the reconstructed image of 100 slices into 10 sections.

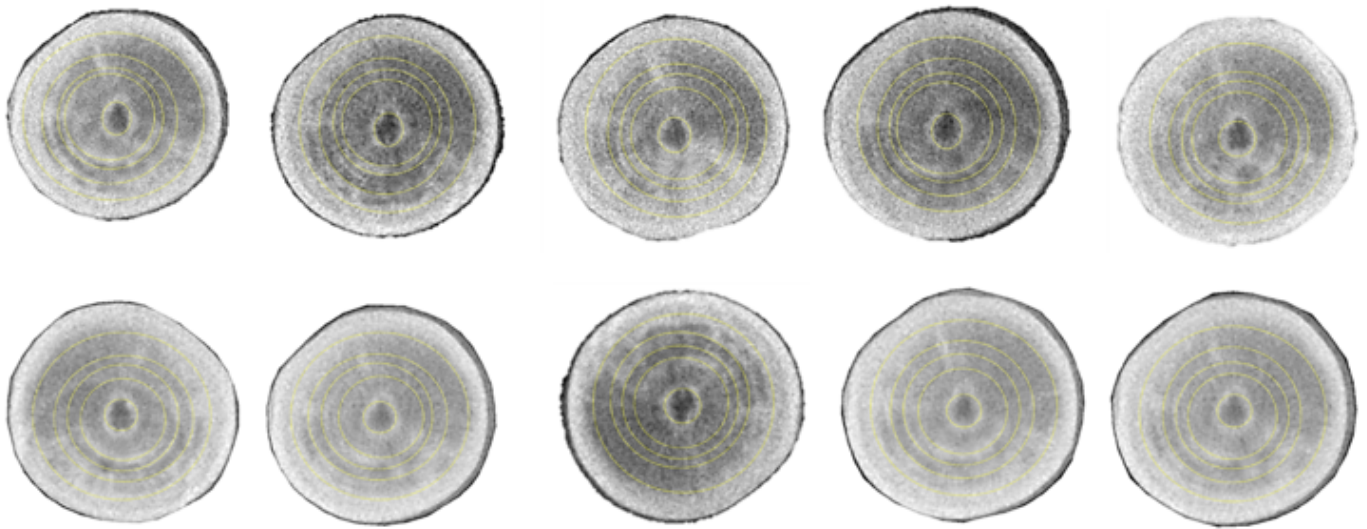


Figure 10

Mapping of Tree Ring Circles on *Angsana* tree Branch Wood.

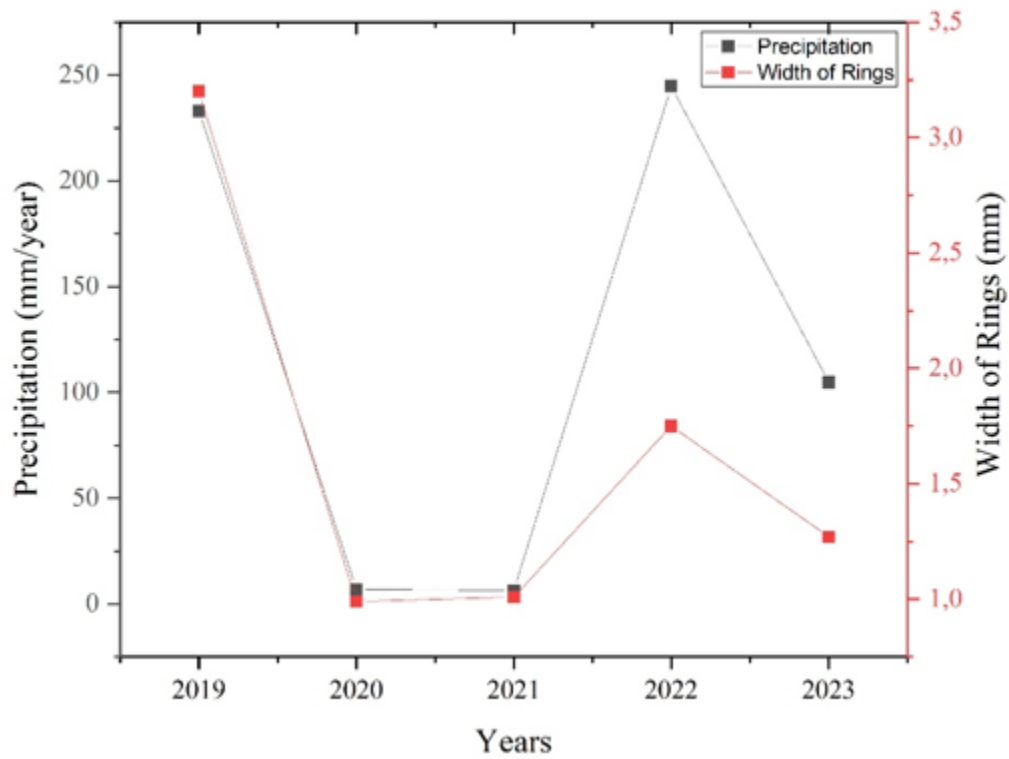


Figure 11

Graph illustrating the relationship between precipitation and the growth of *Pterocarpus indicus* branch rings. The average plot data indicates that the amount of rainfall can affect the growth characteristics of

the wood ring width on *Pterocarpus indicus* branches. The left y-axis represents precipitation, while the right y-axis represents the tree ring width values.

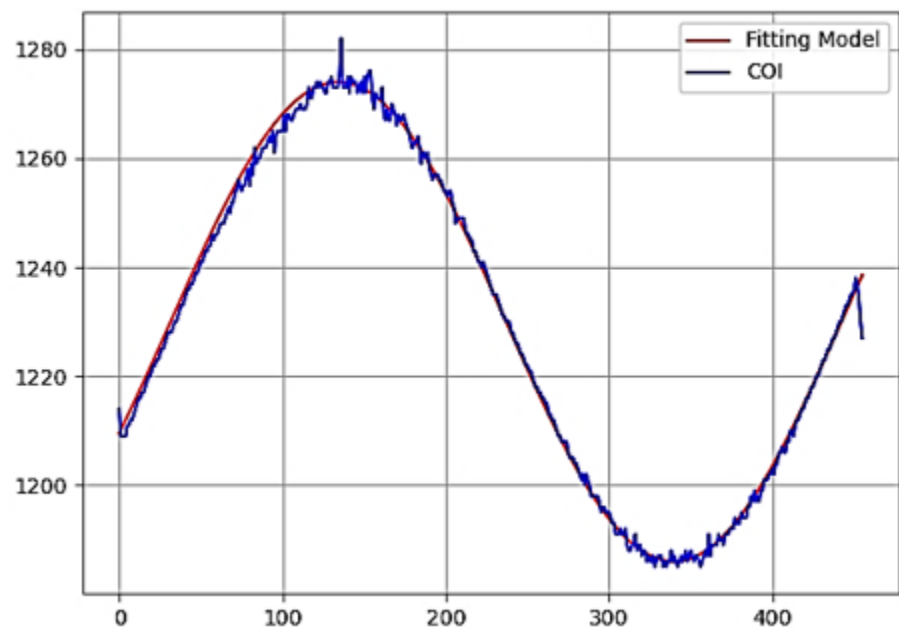


Figure 12

A COI model fitting graph for industrial CT- image projections. The model fitting graph is adjusted for frequency, phase difference, and amplitude to form a sinusoidal wave, ensuring precise image quantities for 3D reconstruction.