



ESTIMATION OF WOOD VOLUME UNDER BARK USING THE BARK FACTOR OF *PINUS BRUTIA* TEN. GROWN NATURALLY IN ZAWITA FOREST

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ABSTRACT

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This study aimed to estimate the under-bark wood volume of *Pinus brutia* Ten. naturally growing in the Zawita region of Dohuk Governorate, Kurdistan Region of Iraq. This research matters because timber is typically marketed after bark removal, while the bark itself also has considerable economic value in the chemical and pharmaceutical industries. Field data were collected from 50 carefully selected trees, including measurements of diameter at breast height (dbh), total and commercial height, and bark thickness at different points along the stem. Mathematical and statistical models were applied, including Mayer's method to calculate the bark factor (k) and regression models to estimate bark thickness based on dbh. The results showed that the best model for predicting bark thickness was a simple nonlinear regression model based on dbh. The bark factor value for *Pinus brutia* Ten. in Zawita was 0.88. Standard under-bark volume tables were developed using dbh and merchantable height, allowing accurate estimation of net wood volume without felling the trees. The study concludes that integrating the bark factor with regression-based models offers a practical and efficient approach for estimating both wood and bark volumes, supporting sustainable forest management and the economic assessment of timber resources in accordance with market standards.

INTRODUCTION

Natural forests are a rare and expendable natural resource if misused. Natural forests are found in various environments north and south of the equator. They are the main source of raw materials for many industries. Forests also reduce the impact of greenhouse gases and mitigate the effects of climate change. Despite the great benefits that forests provide to humanity, they are exploited unjustly to obtain raw materials, especially timber, which is the most important product in forests. Due to the increasing demand for timber and the lack of genuine alternatives, it has become essential to be highly accurate in estimating timber volume. (Munther *et al.*, 2025).

Pinus brutia Ten., also known as Turkish pine, is a species of pine tree widely distributed in the Mediterranean basin and used medicinally in Cyprus, Syria, Lebanon, Iraq, Turkey, Greece, and Iran, where it thrives in diverse and unfavorable conditions (Vasilescu, 2024). In the Kurdistan Region, the *Pinus brutia* Ten. grows in pure or mixed forests alongside oak trees and is of great

environmental and touristic importance. According to (Berendt *et al.*, 2021), this species is considered one of the most important native species in the region, as it contributes significantly to forest cover and biodiversity.

In Iraq, *Pinus brutia* Ten. is naturally found in the northern part of Duhok Governorate, specifically in the mountainous Zawita region. This area is characterized by its steep slopes, rugged terrain, and high altitudes, providing a suitable environment for the growth and development of this species. The total area covered by *Pinus brutia* Ten. forests in this region exceeds 50,000 hectares, this makes it one of the largest natural pine forests in the country (Berendt *et al.*, 2021).

Morales-Molino *et al.* (2021) noted that *Pinus brutia* Ten. trees have adapted to various harsh environmental conditions, such as drought during hot summers and cold, wet winters, and thanks to these capabilities, they are more suitable for carrying out afforestation and reforestation projects, especially in degraded lands or desertified areas. Its rapid growth, drought resistance, and strong root system contribute to soil stability, structure, and local productivity. However, proper management practices are essential for maintaining the ecosystem and ensuring the sustainability of this species' productivity (Beram, 2023).

Pine wood is used in many industries, such as furniture making, decoration, and paper production. The wood is typically sold and marketed after the bark is removed from the main trunk, requiring a precise estimate of the amount of wood beneath the bark. Furthermore, the bark itself can be of high economic value, as it contains extracts used in various chemical and pharmaceutical industries. The bark is the protective shield of the main stem. The thickness and size of the bark are affected by many biotic and abiotic factors, such as tree species, diameter, height, age, genetic characteristics, climatic conditions, and site soil (Sedmikova *et al.*, 2020).

Standgard and Walsh (2011), Graves *et al.* (2014), and Berrill *et al.* (2020) have studied the estimation of bark thickness. Most estimation methods rely on preparing mathematical models of crustal thickness at a height of 130 cm above ground level (dbh) or along the trunk at intervals of 1.0 or 2.0 meters. In practice, both over-bark and under-bark diameters have been suggested as explanatory variables for predicting bark thickness (Kurt *et al.*, 2021). Accurate estimation of bark thickness is essential not only for obtaining precise diameters and wood volumes but also for calculating bark volume, which has gained increasing importance due to its commercial value as a fuel source and as a raw material for bio-based products (Hansen *et al.*, 2023; Temesgen *et al.*, 2015), as well as for medical applications (Zhao *et al.*, 2021). Bark is generally richer in nutrients than wood, and its estimation is also crucial for whole-tree biomass calculations, particularly in forest carbon stock assessments. (Diamantopoulou *et al.* 2018)

Given the absence of any study that has prepared volume tables estimating under-bark wood in Iraq, this study came to achieve several objectives (developing a mathematical model to estimate bark thickness based on dbh, determining the bark modulus (K) using the Meyer method to estimate under-bark wood volume without cutting down trees, and building a standard table of under-bark wood volume for Turkish pine trees in the Zawita forest).

MATERIALS AND METHODS

This study was carried out in Zawita, one of the districts of Duhok Governorate within the Kurdistan Region of Iraq. The area lies at the intersection of longitude 43.1469°E and latitude 36.9066°N, with elevations ranging from 782 to 948 meters above sea level. The district center is located about 17 km from Duhok city (Figure 1). The study area covers 588 hectares and is characterized by its mountainous nature, with abundant valleys and water springs, and is naturally populated with pure Turkish pine trees.

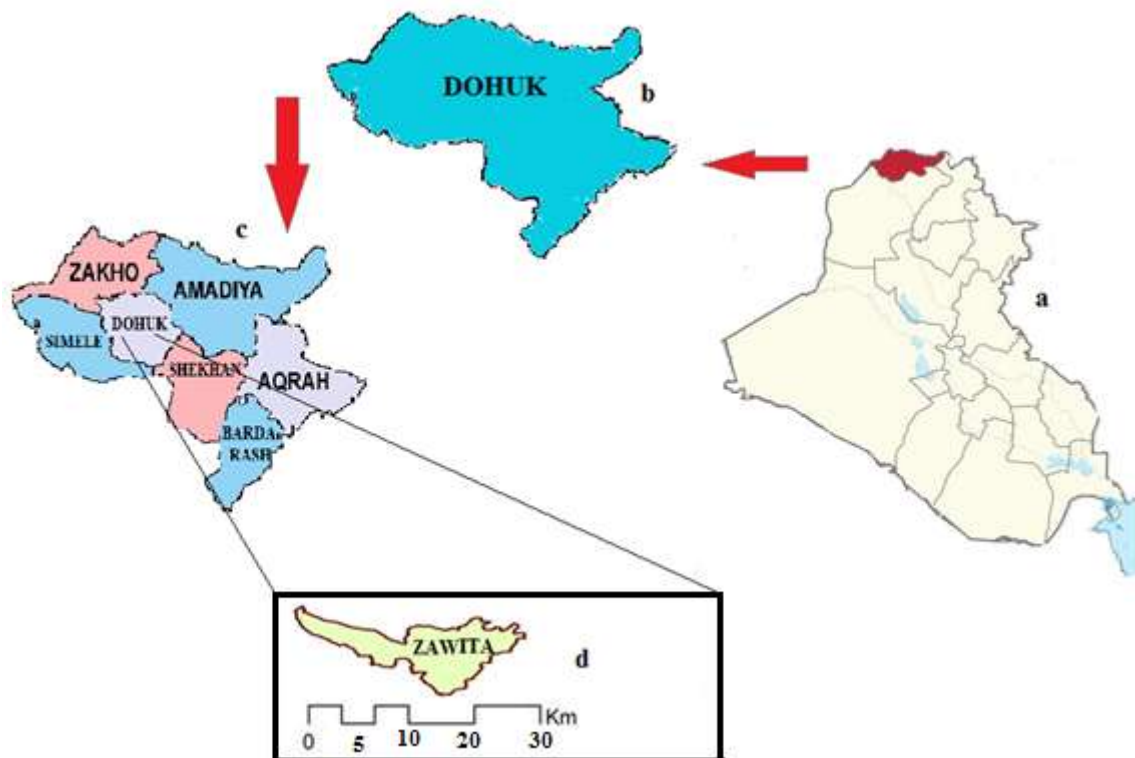


Figure (1): Map of the study area showing: a: the location of Duhok Governorate on the map of Iraq, b: the administrative boundaries of Duhok Governorate, c: the boundaries of the districts of Duhok Governorate, and d: the boundaries of Zawita sub-district.

Data Collection:

Fifty Turkish pine trees were selected selectively, meaning carefully chosen specimens, ensuring they were healthy, free from diseases, pests, and mechanical damage, and that they had ideal growing conditions (Mohammed *et al.*, 2024). The

dbh (diameter at breast height) range was 8–82 cm to represent the full forest population. Measurements were taken for all sample trees, including: Diameter at breast height (to the nearest 0.1 cm) using a caliper, Total tree height using a Haga altimeter, Bark thickness at dbh using a Swedish bark gauge, and Diameters at various stem heights, starting from 0.3 m and at every 1m interval up to the merchantable height (defined as the height where the minimum usable diameter is 4 cm).

All data were recorded in pre-prepared field forms. Tree volume was estimated using the Smalian's formula as follows:

$$V_s = (L/2) \times 0.00007854 \times (d_s^2 + d_L^2) \text{ ----- (1) (West, 2015)}$$

Where: V_s = stem volume by Smalian's method (m^3), L = length of the stem section (m), d_s^2 = square of the smaller-end diameter (cm^2), d_L^2 = square of the larger-end diameter (cm^2).

Bark factor (K) was determined using Meyer's method. To calculate K, bark thickness was measured for all trees (West, 2015), and the under-bark diameter was derived using the equation:

$$dub = dob - 2b \text{ ----- (2)}$$

Where: dub = under-bark diameter (cm), dob = over-bark diameter (cm), $2b$ = double bark thickness (cm)

Then the data collected in the field and calculated in the office were entered into a table for the purpose of organization and to use this data in the future to prepare mathematical models to achieve the study objectives, as in Table (1).

Table (1) Data collected from the Turkish pine trees in Zawita.

No.	dob (cm)	H _m (m)	V _{ob} (m ³)	b(cm)	2b(cm)	dub(cm)
1	32	12.3	0.42131	2.1	4.2	27.8
2	32.8	12.7	0.37737	2.2	4.4	28.4
3	29.6	11.52	0.31424	1.9	3.8	25.8
4	29.7	11.4	0.29539	1.8	3.6	26.1
5	31.1	10.4	0.34546	2	4	27.1
6	18.9	10.92	0.09294	1.3	2.6	16.3
7	21	8.75	0.09633	1.4	2.8	18.2
8	28	11.8	0.24462	1.8	3.6	24.4
9	21	8.11	0.14691	1.5	3	18
10	17.6	6.3	0.07477	1.1	2.2	15.4
11	29.3	12	0.31277	2	4	25.3
12	37.1	14.5	0.52203	3	6	31.1
13	13.2	10.5	0.13004	0.8	1.6	11.6
14	18.8	8.76	0.10248	1.5	3	15.8
15	15.1	7.5	0.04849	0.9	1.8	13.3
16	16.1	8.7	0.07914	1	2	14.1
17	29	8.51	0.23006	1.8	3.6	25.4
18	13.5	9.12	0.05002	0.7	1.4	12.1

No.	dob (cm)	H _m (m)	Vob (m ³)	b(cm)	2b(cm)	dub(cm)
19	8.2	5.2	0.01422	0.5	1	7.2
20	14.4	5.76	0.0422	0.8	1.6	12.8
21	21.7	8.5	0.11707	1.7	3.4	18.3
22	9.5	6.85	0.025	0.5	1	8.5
23	19	10.6	0.42926	1.3	2.6	16.4
24	16.4	8.14	0.10248	0.9	1.8	14.6
25	14.1	8.67	0.06078	0.8	1.6	12.5
26	11.4	6.1	0.03215	0.6	1.2	10.2
27	21	12.48	0.1883	1.4	2.8	18.2
28	16.4	9.24	0.18602	1	2	14.4
29	17.6	8.25	0.09468	1.3	2.6	15
30	16.8	9.12	0.07821	1.4	2.8	14
31	41.5	11.7	0.34579	2.6	5.2	36.3
32	37.3	10.5	0.38456	2.3	4.6	32.7
33	59	14.5	0.52084	3.7	7.4	51.6
34	40.9	13.9	0.49081	2.6	5.2	35.7
35	26.4	18	0.5328	2.1	4.2	22.2
36	19.7	13.8	0.30021	0.9	1.8	17.9
37	48.8	16	0.59994	4.1	8.2	40.6
38	37.2	13.4	0.40032	2.1	4.2	33
39	46.2	14	0.5553	2.7	5.4	40.8
40	64.1	17	0.54021	2.9	5.8	58.3
41	54	16.1	0.6798	2.6	5.2	48.8
42	81.5	20.5	1.1089	4.2	8.4	73.1
43	50	16	0.62182	2	4	46
44	51.8	20.2	0.73002	3.4	6.8	45
45	69	20.2	0.56011	3.6	7.2	61.8
46	50.2	18	0.66232	3	6	44.2
47	48.3	13	0.57012	2.7	5.4	42.9
48	57.5	14.2	0.71119	3.6	7.2	50.3
49	63.4	17	0.82344	4	8	55.4
50	59	14.5	0.72902	3.7	7.4	51.6
Min.	8.2	5.2	0.01422	0.5	1	7.2
Max.	81.5	20.5	1.1089	4.2	8.4	73.1

Afterward, Meyer's relation was applied to calculate the bark factor K.

$$K = \frac{\sum \text{dub.dob}}{\sum \text{dob}^2} \quad \text{----- (3)}$$

Estimating the volume of wood under bark :

The formula to estimate under-bark volume using bark factor k without the need to Harvest trees as follows:

$$Vub = 0.00007854 \times \text{dub}^2 \times L \quad \text{----- (4)}$$

$$Vob = 0.00007854 \times \text{dob}^2 \times L \quad \text{----- (5)}$$

$$\mathbf{dub} = \mathbf{k} \times \mathbf{dob} \text{ ----- (6)}$$

Where: **Vub** = under-bark stem volume (m³), **Vob** = over-bark stem volume (m³), **dub** = under-bark diameter (cm), **dob** = over-bark diameter (cm), **L** = stem length (m), **k** = bark factor.

By substituting equation (6) into (4):

$$\mathbf{Vub} = 0.00007854 \times (\mathbf{k} \times \mathbf{dob})^2 \times \mathbf{L}$$

$$\mathbf{Vub} = 0.00007854 \times \mathbf{dob}^2 \times \mathbf{L} \times \mathbf{k}^2$$

$$\mathbf{Vub} = \mathbf{Vob} \times \mathbf{k}^2 \text{ ----- (7)}$$

Equation (7) enables estimating under-bark stem volume of standing trees without felling them, which is crucial for accurate wood volume assessment and sustainable forest management. ,(Bauer *et al.*, 2021)

An equation can be developed to estimate the over-bark stem wood volume based on both diameter and height, commonly referred to as a standard volume table (Muhammad and Al-Yousif, 2023). However, no such tables have been designed to estimate the under-bark wood volume. Therefore, in the present study, standard under-bark volume tables were constructed using a specifically developed mathematical model. These tables aim to provide forest managers and decision-makers with a practical tool for accurately estimating net wood volume.

All models were developed using Statgraphics V18 software and validated by several statistical indicators to ensure accuracy.

Model Evaluation Criteria :

The process of selecting the best model that could best describe the field data was carried out. The conformity quality indicators were tested using several statistical measures that indicate the accuracy of the mathematical model, such as the coefficient of determination (R²), standard error (S.E.), and the Durbin-Watson test (D.W.). Residual analysis was also performed to enhance the reliability of the conformity models.

It is worth noting that the closer the R² value is to one, the better the model. Low S.E. values also indicate a good model, and D.W. values are acceptable within the range of 1.5 to 2.5, with values closer to 2 being the most accurate. As for the residual analysis test, the results are shown as images of the residual distribution, and a random shape of the distribution indicates the goodness of the model. (Sedmikova *et al.*, 2020)

RESULTS AND DISCUSSION

Developing a highly accurate regression equation requires meticulous attention to detail when collecting field data, as the validity of the results depends heavily on the accuracy of the data collected from the forest, the degree to which the samples match the forest population, and whether the sample data encompasses the entire

data range for the variable under study. (Stangle and Dorman, 2018; Munther *et al.*, 2025).

Models for Estimating Bark Thickness:

Field data were used to develop models estimating bark thickness with the aid of the Statgraphics program, as shown in Table (2).

Table (2): Models for estimating the bark thickness b for the pine stands in Zawita

No	Model	R^2	S.E	D.W	b_0	b_1	b_2
1	$b = b_0 + b_1 * dbh$	0.888	0.351	1.9	0.23522	0.054141	
2	$b = b_0 + b_1 * dbh + b_2 dbh^2$	0.906	0.326	2.2	0.24684	0.086565	0.00041
3	$b = b_0 + dbh^{b_1}$	0.906	0.322	2.2	2.15484	0.419519	

Table (2) presents three different regression models estimating bark thickness based on an easily measurable variable—the diameter at breast height (dbh). The models exhibited different coefficients of determination (R^2), which reached 0.888, 0.888, 0.906, and 0.906 for models (1, 2, and 3), respectively. The standard errors were 0.351, 0.326, and 0.322, respectively. Model 3 showed the best statistical indicators of accuracy; therefore, it was selected. To ensure no autocorrelation existed between residuals of predicted and actual values of the dependent variable, residual analysis was performed, as illustrated in Figure (2).

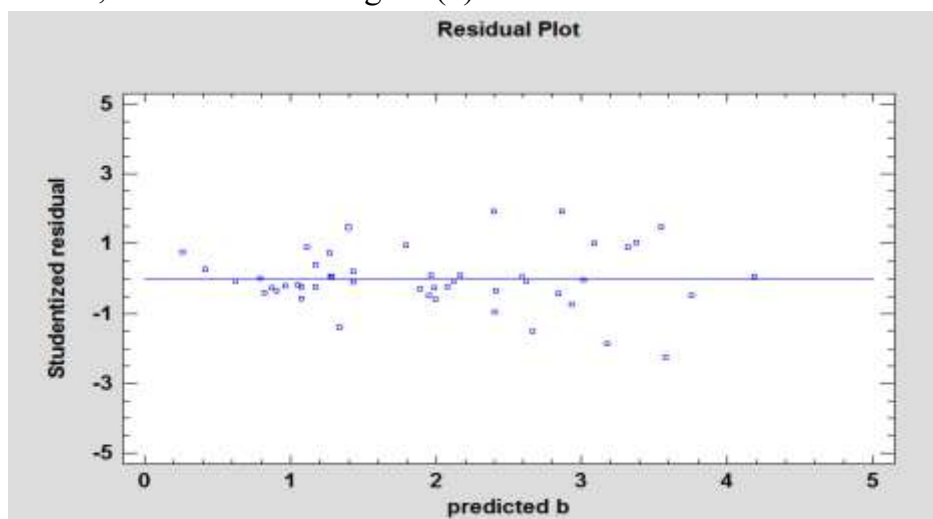


Figure (2): Distribution of residuals between the actual and estimated values of the dependent variable for Model (3).

Figure (2) shown that the residuals are randomly distributed around the zero line, indicating that the assumptions of the test are met and confirming the accuracy of this equation. Therefore, it can be used to estimate bark thickness for naturally occurring *Pinus brutia* stands in Zawita (Figure 3).

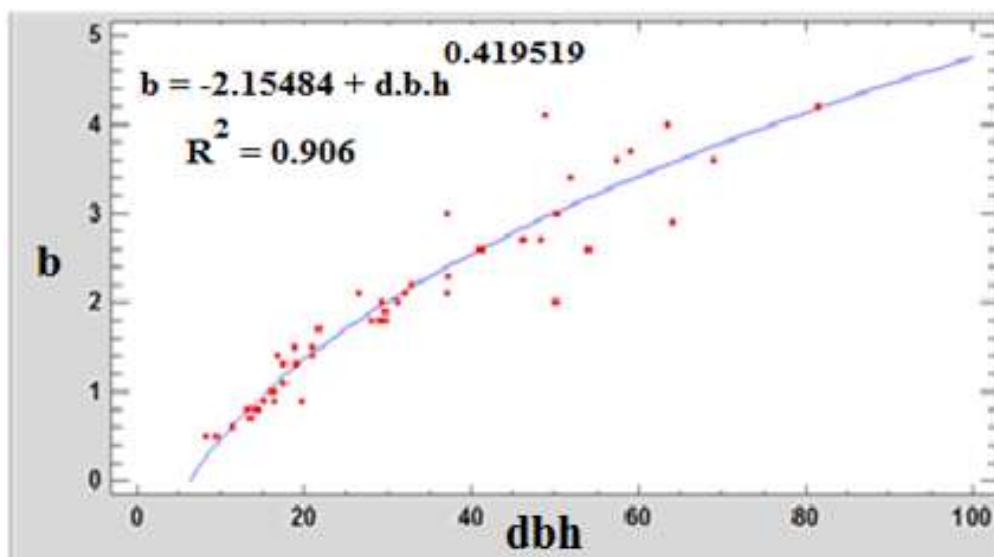


Figure (3): Simple non-linear regression of bark thickness (cm) and dbh (cm) for sample trees.

Figure (3) illustrates that the relationship between bark thickness (dependent variable) and dbh (independent variable) is a positive one. This agrees with findings reported by other researchers (Lowe *et al.* 2024; Krajnc and Gricar, 2020 ;Jankovsky *et al.* 2019). And the non-linear model performed better in describing this relationship.

Estimation of the Bark Factor (k):

Meyer's method was used to determine the bark factor (k) using Equation (3). After deriving the value of k, it was applied to estimate the merchantable wood volume of the main stem using Equation (7). The bark factor determined for *Pinus brutia* stands in Zawita was (0.88).

Preparation of a Standard Under-Bark Volume Table:

Volume tables are generally defined as tools used to estimate the main stem volume of a tree based on one or more measurable variables, such as diameter at breast height (dbh), total height, or form factor (Muhammad & Al-Yousif, 2023). Among these, standard or general volume tables are the most widely applied, as they utilize two easily measurable parameters dbh and height providing a practical balance between accuracy and simplicity. Typically, these tables estimate the wood volume including bark (over-bark volume). However, because timber is commercially processed and sold after bark removal, it is essential to develop volume tables that specifically estimate the under-bark stem volume to better reflect the usable wood content.

In this study, we provided this type of table. Two models were developed to estimate under-bark volume based on dbh and height: a multiple linear regression model and a multiple non-linear regression model (Table 3).

Table (3): Models for estimating the volume of the main stem under bark of the pine trees in Zawita

No.	Model	R ²	S.E	D.W	b0	b1	b2
1	$V_{ub}=b_0+b_1*dbh+b_2*H_m$	0.907	0.063	1.85	-0.18526	0.007027	0.018501
2	$V_{ub}=b_0+dbh^{b_1}+H_m^{b_2}$	0.873	0.074	1.48	-2.74813	0.140651	0.141482

Table (3) shown that the first model was a multiple linear regression, while the second was a multiple non-linear regression. Comparing the statistical metrics of the two models, the first model showed superior statistical indicators ($R^2 = 0.907$, $S.E = 0.063$, $D.W = 1.85$), indicating that the linear model fit the data better than the non-linear model. Therefore, the first model was selected. Residual analysis was conducted to confirm no autocorrelation between the differences of actual and predicted values of the dependent variable, as shown in Figure (4).

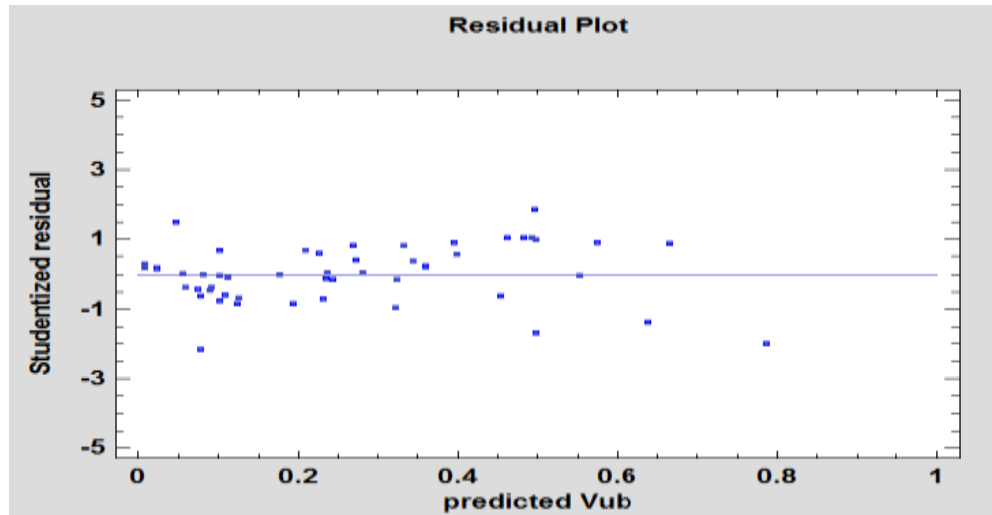


Figure (4): Distribution of residuals between the actual and estimated values of the dependent variable for Model 1.

Figure (4) indicates that the residuals are randomly distributed around the zero line for both negative and positive values, confirming the validity of test assumptions and the quality of the selected model. Therefore, this model was used to prepare a standard (general) under-bark volume table for *Pinus brutia* stands (Table 4).

Table (4): presents the standard under-bark volume table for *Pinus brutia*.

dbh	H _m								
	5	7	9	11	13	15	17	19	21
8	0.0022	0.0031	0.0375	0.0745	0.1115	0.1485	0.1855	0.2225	0.2595
13	0.0203	0.0356	0.0726	0.1096	0.1466	0.1836	0.2206	0.2576	0.2946
18	0.0337	0.0707	0.1077	0.1447	0.1817	0.2187	0.2557	0.2927	0.3297
23	0.0689	0.1059	0.1429	0.1799	0.2169	0.2539	0.2909	0.3279	0.3649
28	0.104	0.141	0.178	0.215	0.252	0.289	0.326	0.363	0.4
33	0.1391	0.1761	0.2131	0.2501	0.2871	0.3241	0.3611	0.3981	0.4351
38	0.1743	0.2113	0.2483	0.2853	0.3223	0.3593	0.3963	0.4333	0.4703
43	0.2094	0.2464	0.2834	0.3204	0.3574	0.3944	0.4314	0.4684	0.5054
48	0.2445	0.2815	0.3185	0.3555	0.3925	0.4295	0.4666	0.5036	0.5406
53	0.2797	0.3167	0.3537	0.3907	0.4277	0.4647	0.5017	0.5387	0.5757
58	0.3148	0.3518	0.3888	0.4258	0.4628	0.4998	0.5368	0.5738	0.6108
63	0.3499	0.387	0.424	0.461	0.498	0.535	0.572	0.609	0.646
68	0.3851	0.4221	0.4591	0.4961	0.5331	0.5701	0.6071	0.6441	0.6811
73	0.4202	0.4572	0.4942	0.5312	0.5682	0.6052	0.6422	0.6792	0.7162
78	0.4554	0.4924	0.5294	0.5664	0.6034	0.6404	0.6774	0.7144	0.7514
83	0.4905	0.5275	0.5645	0.6015	0.6385	0.6755	0.7125	0.7495	0.7865

$$V_{ub} = -0.18526 + 0.00702707*dbh + 0.0185007*H_m$$

$$R^2 = 0.907 \text{ S.E} = 0.063$$

The table shows that the main stem under-bark volume increases with increasing dbh as well as with increasing merchantable height, since both dbh and H_m are tree dimensions with the greatest effect on volume. This agrees with the findings of (Temesgen *et al.*, 2015) (Hansen *et al.*, 2023) (Diamantopoulou *et al.*, 2018).

This table can now be used to estimate under-bark wood volume based on dbh and height. For example, a tree with a dbh of 43 cm and a merchantable height of 19 m have an estimated under-bark wood volume of 0.4684 m³. The developed model and under-bark wood volume table can be applied in forest inventory programs and sustainable forest management planning in northern Iraq.

Conclusions

The study showed that it is possible to develop highly accurate mathematical models to estimate the volume of wood under the veneer without cutting down trees, using the veneer factor. We can also prepare standard volume tables for users to estimate the volume of wood under the veneer using the tree's diameter and height.

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Conflict of Interest

The author declares that they have no financial or non-financial conflicts of interest relevant to the research, authorship, or publication of this article.

تقدير حجم الخشب تحت القشرة باستخدام عامل القشرة لأشجار الصنوبر البروتي *Pinus brutia* Ten. النامية طبيعياً في غابة زاويتا

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الخلاصة

تناول البحث تقدير حجم الخشب تحت القشرة لأشجار الصنوبر البروتي (*Pinus brutia* Ten.) النامية طبيعياً في منطقة زاويتا – محافظة دهوك/ إقليم كردستان العراق. تبرز أهمية هذه الدراسة كون الأخشاب تسوق عادة بعد إزالة القشرة، إضافة إلى أهمية القشرة نفسها في الصناعات الكيميائية والدوائية، تم جمع بيانات ميدانية من 50 شجرة مختارة بعناية، شملت قياس القطر عند مستوى الصدر (DBH)، والارتفاع الكلي والارتفاع التجاري، وسمك القشرة في مواقع مختلفة من الجذع. استخدمت نماذج ومعادلات رياضية وإحصائية، من بينها طريقة ماير لحساب عامل القشرة (k)، وكذلك نماذج انحدار لتقدير سمك القشرة بالاعتماد على القطر عند مستوى الصدر، أظهرت النتائج أن أفضل نموذج لتقدير سمك القشرة هو نموذج الانحدار غير الخطي البسيط المعتمد على القطر عند مستوى الصدر، حيث بلغت قيمة عامل القشرة لأشجار الصنوبر البروتي في زاويتا 0.88، كما تم إعداد جداول حجم قياسية تحت القشرة اعتماداً على القطر عند مستوى الصدر والارتفاع التجاري، مما يتيح تقدير حجم الخشب الصافي بدقة دون الحاجة إلى قطع الأشجار، خلصت الدراسة إلى أن اعتماد عامل القشرة إلى جانب النماذج الإحصائية يوفر أدوات عملية ودقيقة لتقدير حجم الخشب والقشرة على حد سواء، بما يساهم في تحقيق إدارة مستدامة للغابات وتأمين المنتجات الخشبية وفقاً لمعايير السوق وقيمتها الاقتصادية الحقيقية.

الكلمات المفتاحية: سمك القشرة، طريقة ماير، النمذجة، الصنوبر البروتي، جداول الحجم القياسية.

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