BIOMASS AND CARBON TABLES FOR MAJOR TREE SPECIES OF GILGIT BALTISTAN, PAKISTAN

By

Anwar Ali
Forest Mensuration Officer, PFI

FORESTS, WILDLIFE AND ENVIRONMENT DEPARTMENT, GILGIT BALTISTAN, GILGIT
&
PAKISTAN FOREST INSTITUTE, PESHAWAR
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DATA COLLECTION TEAM

Anwar Ali, Forest Mensuration Officer, PFI
Muhammad Iftikhar, SDFO, GB Forest Department
Sajjad Ahmad, RFO, GB Forest Department
Muhammad Tufail, Field Assistant, PFI

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Introduction

Forest play important role in climate change as they act as sink as well as source of carbon emissions. Forests sequester CO_2 from the atmosphere through photosynthesis and store this carbon in the form of biomass and soil organic matter in the forest ecosystem. On the other hand, forests also contribute substantially to global carbon emissions. They release about 1.6 billion tonnes of carbon annually to the atmosphere. About 17% of GHG emissions are contributed by deforestation and degradation of forests (IPCC, 2007).

With emergence of REDD+, the focus of forest management is being shifted towards carbon sequestration. Under UNFCCC, the parties are required to report their emissions in forestry sector. For more accurate and precise estimates, reporting level at Tier 2 and Tier 3 are required which need local emission factors. Development of local emission factors for forest carbon accounting involves development of local wood density values, biomass expansion factors and local allometric equation for biomass estimation.

Gilgit-Baltistan is situated in the extreme north of Pakistan, bordering China and Afghanistan in the north (35˚-37') and India in the east (72˚-75'), covering an area of 72,496 square kilometers. The whole area falls within the high mountain ranges of Karakorum, Himalayas, Hindukush and Pamir with most of the area situated at or above 4,500 meters above sea level.

Climatic conditions vary widely in the Gilgit Batistan, ranging from the monsoon-influenced moist temperate zone in the western Himalaya, to the arid and semi-arid cold desert in the northern Karakoram and Hindu Kush. Below 3,000 m, precipitation is minimal, rarely exceeding 200 mm annually. However, there is a strong gradient with altitude, and at 6,000 m, the equivalent of 2,000 mm per year falls as snow. Temperatures in the valley bottoms can vary from extremes of 40°C in summer to less than –10°C in winter (Govt. of Pakistan, 2003). The total forest area of Gilgit Baltistan is 337,491 ha. Major forest tree species of GB include *Cedrus deodara* (Deodar), *Pinus wallichiana* (Kail), *Abies pindrow* (Fir), *Picea smithiana* (Spruce), *Pinus gerardiana* (Chilghoza) and *Quercus ilex* (Oak).

Biomass tables are prepared using different allomteric equations based on regression models. These biomass tables contain information on green and dry biomass over bark, green and dry biomass under bark and dry biomass of bole, branches and brushwood for 2 cm dbh classes. The oven-dried biomass estimates are also converted into carbon stock estimates and shown against each dbh class in the tables. Age of trees determined through ring counting of the stumps is also presented against dbh classes. Information on basic wood density and Biomass Expansion Factors are also available in the document. Allometric equations estimate dry biomass from one or more independent variables, basic wood density is the ratio of oven dry biomass to green volume. BEF is a factor that expands the dry-weight of *growing stock biomass* to account for non-merchantable or non-commercial biomass components, such as stump, branches, twigs and foliage.

Though these biomass tables are primarily applicable to the forest areas of Gilgit Baltistan, however, these can also be applied to the same tree species in other dry temperate areas with similar ecological conditions such as Kohistan, Chitral and FATA. Biomass tables for other ecological regions can be developed on the procedure adopted in the current research.

The biomass tables and equations will help forest resource managers and researchers to accurately estimate carbon stock and carbon emissions from their respective forest areas. Thus they can participate in REDD+ and other carbon trading schemes to earn carbon credits and contribute in global climate change mitigation.

DATA COLLECTION

Selection of Sample Trees

Data for development of allometric equations was collected through destructive sampling of trees scattered throughout GB as shown in the map. The total biomass of a tree and its components cannot be determined accurately unless the tree is cut and the components are measured weighed. Therefore, destructive sampling had to be resorted to. However, due to unique value of Chilghoza pine (*Pinus gerardiana*) due to its nuts, non-destructive method was adopted to indirectly estimate the biomass of the species. As felling and logging of sample trees is a tedious job and involve destructive sampling, the sample size was kept as low as possible. In total 144 trees were selected for the study. DBH ranged from 8 cm to 123 cm. Sample trees were arranged in diameter classes of 5 cm from 6 to 125 cm. For determination of height functions, additional trees were measured to cover any variation in height due to site quality, slope and aspect. The location of sample trees is shown in Figure 1. For each species, 2-3 sample trees per DBH class were randomly selected, felled and measured for data collection. Efforts were made to select trees of normal form and shape to closely represent the forest stands of the area. Trees with broken top, forked stem, excessive or less branching or any other abnormality were avoided. The detail of sample trees is given in the following table.

Table 1. Detail of sample trees used in the preparation of local biomass tables

Species	Range of dbh (cm)	Range of heights (m)	Number of sample trees
Cedrus deodara	8-123	4.5-42	32
Pinus wallichiana	8-110	5-45	25
Pinus gerardiana	8-65	4.5-19.8	36
Abies pindrow	6.5-100	4.5-27.5	22
Picea smithiana	9-73	5-37	16
Quercus ilex	16-40	4.8-10.6	13
Total			144

A Deodar Tree felled for biomass estimation in Chilas

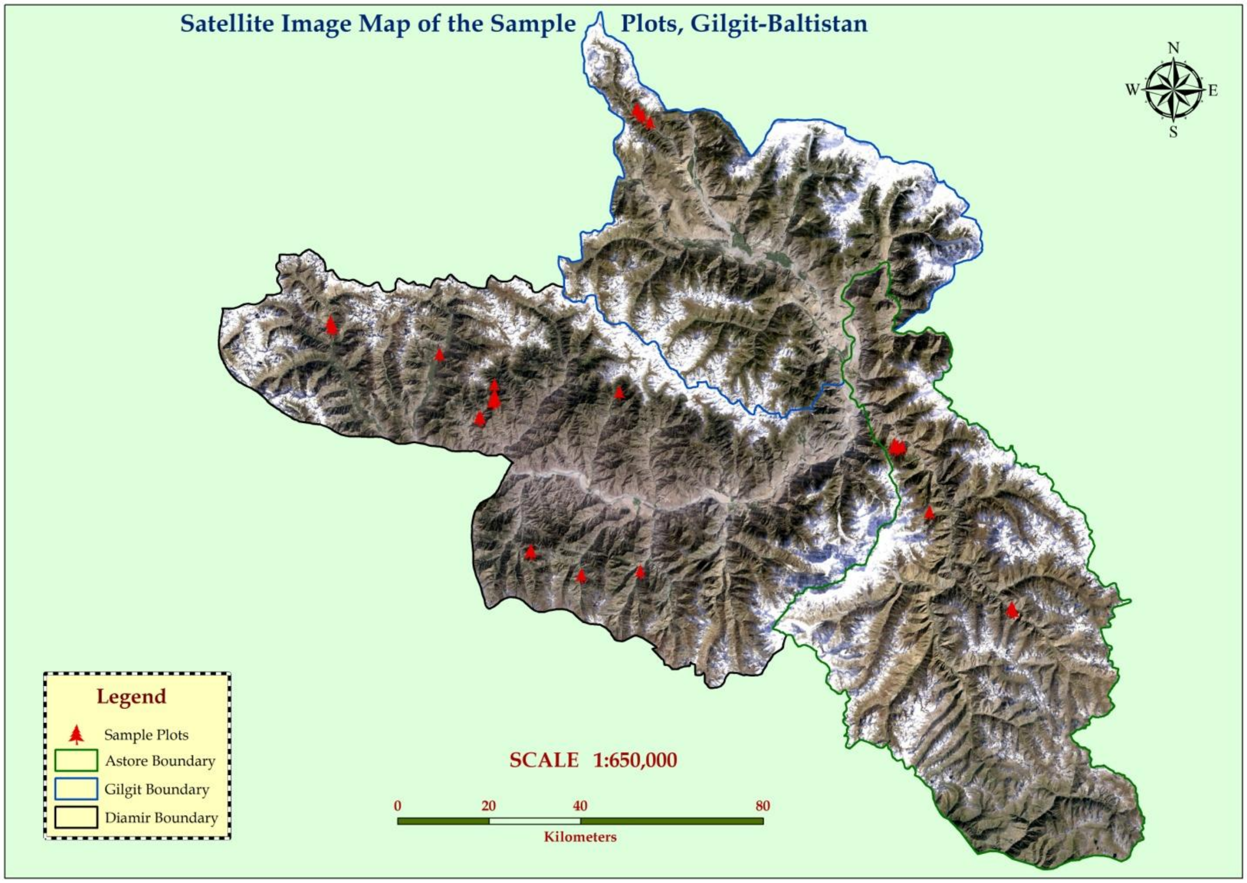

Figure 1: Location of Sample Trees

Methods and Procedure of Measurement

Diameter at Breast Height (DBH) and total height of the sample tree were measured before felling. Point of DBH was marked on stem at 1.37 m (4.5 feet) aboveground on uphill side and DBH was measured with dia tape upto one decimal in centimeter. Total height of the standing tree from ground to tip of the leading shoot was measured in meters upto two decimals with clinometer or relaskop. The sample trees were felled with the help of a chain saw as close to the ground as possible in a pre-decided direction to minimize damage to other trees. After felling the total height was re-measured with a measuring tape and recorded on the proforma (Annex-I). Bole heights upto 20 cm diameter and 5 cm diameter were measured for determining timber height and small wood height respectively. Age of the tree was determined through counting of annual rings on the stump. Besides, stand type, stand density, altitude, aspect and coordinates were also recorded with the help of a GPS.

After felling, the branches and leaves were removed from the stem. Small branches upto 5 cm diameter at thin end were separated. Brush wood- branches with dia less than 5 cm alongwith leaves/needles- was separated. Fresh weight of branches and brushwood were recorded separately. Samples were taken from branches and brushwood and packed in bags for oven drying in the Laboratory. The stem was converted into 2 m logs with end log of variable length. The over bark mid diameter of the log and its length were measured for determining volume of logs using Huber's formula. The fresh weight of each log was measured on the spot with the help of a digital weighing machine. However, some of the logs were too heavy to be lifted and directly weighed on the scale, so small discs were cut from the logs. Volume and fresh weight of these discs were determined on the spot and these discs were brought to laboratory for oven drying. The densities of the discs were applied to the volume of the logs to determine their biomass.

The samples of boles, branches and brushwood and bark were dried in the oven at 105^0C until they attained a constant weight. The dry to fresh weight ratios were applied to calculate the dry biomass of stems, branches and brushwood of the whole tree (Mandal et al., 2013).

Weighing of Brushwood

Weighing of logs in the field

Method adopted for biomass estimation of Chilghoza Pine (*Pinus gerardiana*)

Due to high commercial value of Chilghoza pine due to its nuts, the local community has imposed complete ban on its felling in Gilgit Baltistan. In this situation it was not possible to go for destructive sampling of the species. An indirect method was applied for biomass estimation of Chilghoza pine. The volume of the sample trees were assessed in standing position. For this purpose the services of skilled climbers were hired. As the Chilghoza tree does not attain much height, it is easy to climb the tree and take measurement of bole and branches. The DBH and total height of the sample trees were measured as per procedure described under the previous section.

The tree bole was marked at every 2 m above DBH and the mid diameter of the logs were measured using diameter tape. The volume of each section was measured using Huber's formula and summed up for the bole. Similarly length and mid diameter of all the branches were measured for calculating their volume. The volume of the branches was added with that of the bole to get total volume of the tree in cubic meter. Few big branches were cut to get discs for determining density of the tree. The discs were taken to laboratory for drying in the oven and the basic wood density was determined for Chilghoza pine. The value of density was multiplied by the total volume of the sample trees to calculate their biomass.

Measurement of standing tree of Chilghoza

Determination of densities and moisture contents

Three to five discs of 10 cm thickness were taken from base, middle and top of the bole of every sample tree. These discs were marked with species, tree No. and section No. (S_1, S_2, S_3) before taking their fresh weights. The fresh weight of each disc was measured in grams with the help of a digital balance in the field both with and without bark. The bark green weight was determined by subtraction. The discs and barks were put in bags and brought into laboratory. The volume of the discs were again measured through water displacement method in the Xylometer to determine their volumes in cubic centimeter. The discs were dried in the oven at 105^0 C till they gained constant weight. After drying in the oven, the weights of the discs were measured and recorded on a proforma given at Annex II. The Basic Wood Densities of the discs were calculated by the following formula:

$$\text{Density of specimen} = \text{Dry Weight in gm/Fresh Volume in cc}$$

Basic wood densities were recorded in gram/cubic centimeter.

The moisture contents of the bole discs and samples of branches and brushwood were calculated as below:

$$MC\% = \{\text{Dry weight}/ (\text{Fresh weight} - \text{Dry weight})\}x100$$

The dry wood % was determined by the difference i.e. 100-MC%. The basic wood densities and moisture contents were recorded for all specimens and averaged.

Determination of volume of disc

Determination of fresh weight of disc

Drying in the oven

Model Fitting

Several allomteric equations have been developed by researchers to estimate biomass of different tree species using several variables as predictors or independent variables. DBH, total height, volume, basal area, density and crown radius are the common variables used for estimation of tree biomass. However, DBH is the most commonly used independent variable for biomass estimation due to ease in measurement and being strongly correlated with tree volume and biomass. DBH alone can be used as a single biomass predictor in allometric models. When combined with other variables such as total height and density the estimates could be improved in some cases. The following regression models were tested in the current study.

	Model	**Description**
1.	$M = a+bD$	Linear
2.	$M = a+bD^2$	Basal Area
3.	$M = a+bD+cD^2$	Parabolic
4.	$M = a+bD^2H$	Combined variable
5.	$\ln M = a+bD$	Exponential
6.	$M = aD^b$	Power Law
7.	$M = a(D^2H)^b$	Power Law combined
8.	$M = a(pD^2H)^b$	Power Law combined

Where

M = Dry Biomass of tree in Kg

D = Diameter at Breast Height in cm

H = Total height of tree in m

p = Basic wood density or specific gravity

ln = Natural Logarithm

a = regression constant

b, c = regression coefficients

The above models were used for estimation of total dry biomass separately for each species.

Models evaluation and selection

The above mentioned models were evaluated for their reasonability, efficiency, practicability and statistical validity. A model is considered reasonable if it yields estimates with minimum standard error (SEE), minimum sum of square of the residual error (SSE) throughout the range of data, does not give negative estimates and does not show decrease in biomass with increase in D or H. The equation is considered efficient if it yields accurate estimate and controls the bias. The estimates beyond the range of data i.e. extrapolated values should not be unrealistic or exaggerated. The equation is practicable if it is easy to calculate and use meaning that the equation should not depend on a large number of variables. Statistical validity is judged on the basis of the 'indices of best fit' including R^2 which is the determination coefficient and can be interpreted as being the ratio between the variance explained by the model and the total variance. It is between 0 and 1, and the closer it is to 1, the better the quality of the fit. On the other hand, SSE and SEE should be minimum whereas F and P values of the models should be significant.

All regression models used for biomass estimation are based on three hypotheses- the residuals are independent, follow a normal distribution and have constant variance. The hypothesis that the residuals are normally distributed can be checked visually by inspecting the quantile–quantile graph which shows the empirical quantiles of the residuals against the theoretical quantiles of the standard normal distribution. If the points are approximately aligned along a straight line, then the hypothesis is satisfied. The hypothesis of constant variance can be checked visually by plotting the cluster of points for the residuals against predicted values. If the variance of the residuals is indeed constant, this cluster of points should not show any particular trend or structure (Picard et al., 2012).

Beside the above statistical tests the percent bias (PBIAS) of the models were also applied to compare and evaluate the predicted values and observed values for accuracy assessment using the following formula:

$$PBIAS = \sum(Xobs-Xpre)*100/ \sum Xobs$$

Where, Xobs is observed value and Xpre is predicted value derived from equation (Mandal *et al*., 2013).

All the data analysis was performed in MS Excel and SPSS 16.

Final Selection of Models

All the first seven models were tested for all species and the model which showed best performance on the following criteria was finally selected. For Deodar, Kail, Fir and Spruce a general biomass equation was developed on the basis of regression model No.8. The equations alongwith indices of best fit for the selected models are given in the following table.

i) Minimum sum of square of the residual error
ii) Minimum standard error of the estimate
iii) Maximum value of R^2

The estimates yielded by the selected models were compared with already published models (e.g Chave et al., 2005, West et al., 2003) and the estimates obtained from applying wood density and biomass expansion factors.

Out of different models tested for biomass estimation of all the species, Model No.7 yielded the best fit for individual species as per the given criteria. However in case of Chilghoza pine, both models No.6 and Model No. 7 were almost equally good. Inclusion of tree height in the model (Model 7) did not improve the biomass estimates, rather DBH was found to be the single strong predictor of the biomass. Therefore, model with only DBH as the predictor (Model No.6) was preferred for Chilghoza pine. The graphical representations of the selected models are shown in figures.

Table 2. Regression Models selected for biomass estimation

Species	Regression Model	Allometric equation	N	SEE	F value	P value	SS of Residuals	R^2
General (Coniferous species)	$M = a(pD^2H)^b$	$M= 0.1645(pD^2H)x^{0.8586}$ M = exp{-1.8047+0.8586Ln(pD2H)}	95	0.252	3979	0.000	5.911	0.977
Cedrus deodara (Deodar)	$M = a(D^2H)^b$	$M= 0.1779(D^2H)^{0.8103}$ or M = exp{-1.7264+0.8103Ln(D2H)}	32	0.183	1929	0.000	1.010	0.985
Pinus wallichiana (Kail)	$M = a(D^2H)^b$	$M= 0.0631(D^2H)^{0.8798}$ or M = exp{-2.7638+0.8798Ln(D2H)}	25	0.150	3213	0.000	0.520	0.993
Pinus gerardiana (Chilghoza)	$M = aD^b$	$M = 0.0253D^{2.6077}$ or M = exp{ -3.6764+ 2.6077LnD}	35	0.306	714.87	0.000	3.087	0.955
Abies pindrow (Fir)	$M = a(D^2H)^b$	$M= 0.0954(D^2H)^{0.8114}$ or M = exp{ -2.3495+0.8114Ln(D2H)}	22	0.157	2052	0.000	0.496	0.990
Picea smithiana (Spruce)	$M = a(D^2H)^b$	$M= 0.0843(D^2H)^{0.8472}$ or M = exp{ -2.4729+0.8472Ln(D2H)}	16	0.129	2277	0.000	0.234	0.994
Quercus ilex (Oak)	$M = a(D^2H)^b$	$M= 0.8277(D^2H)^{0.6655}$ or M = exp{-0.1891+0.6657Ln(D2H)}	13	0.232	72.782	0.000	0.594	0.868

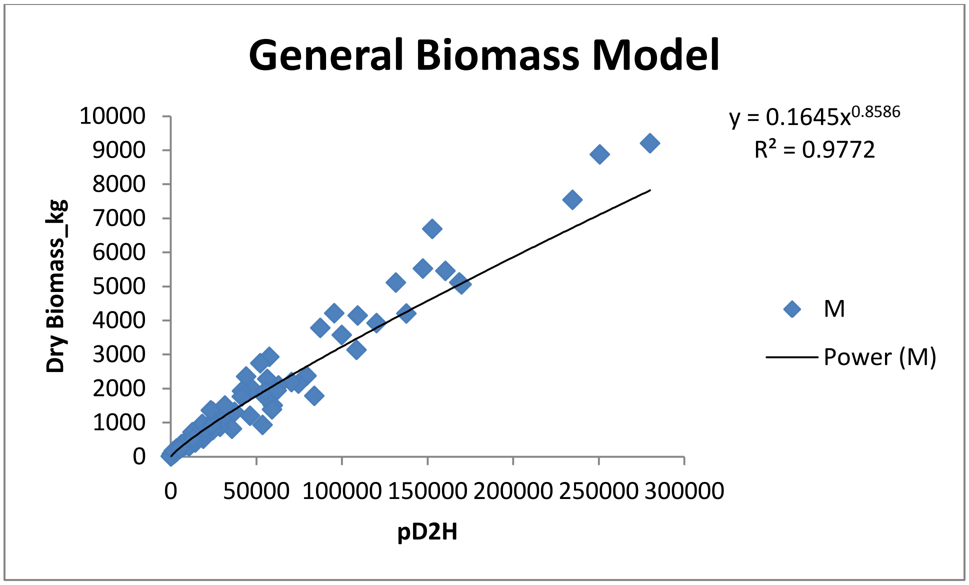

Figure 2. General Biomass Model for Coniferous Species

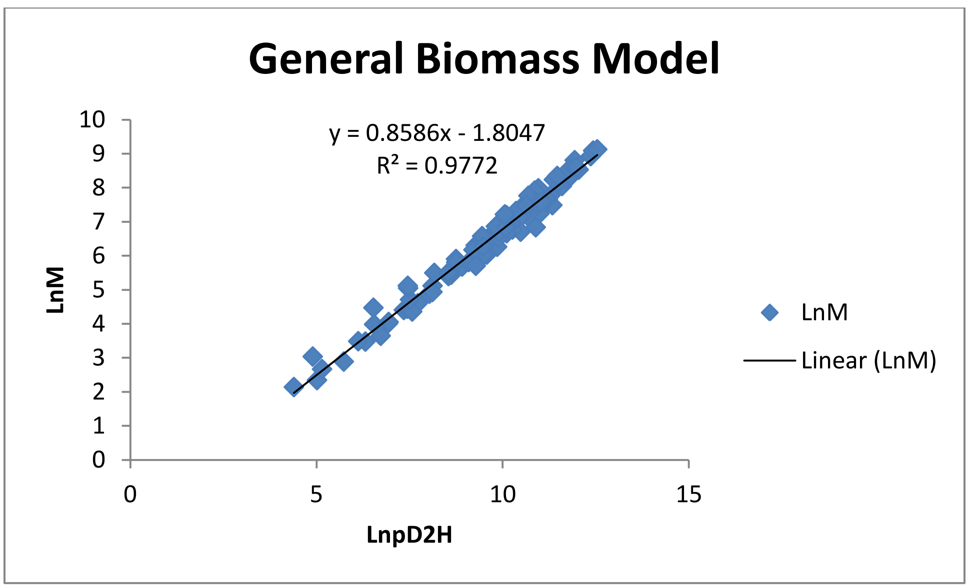

Figure 3. General Biomass Model (Log Transformed) for Coniferous Species

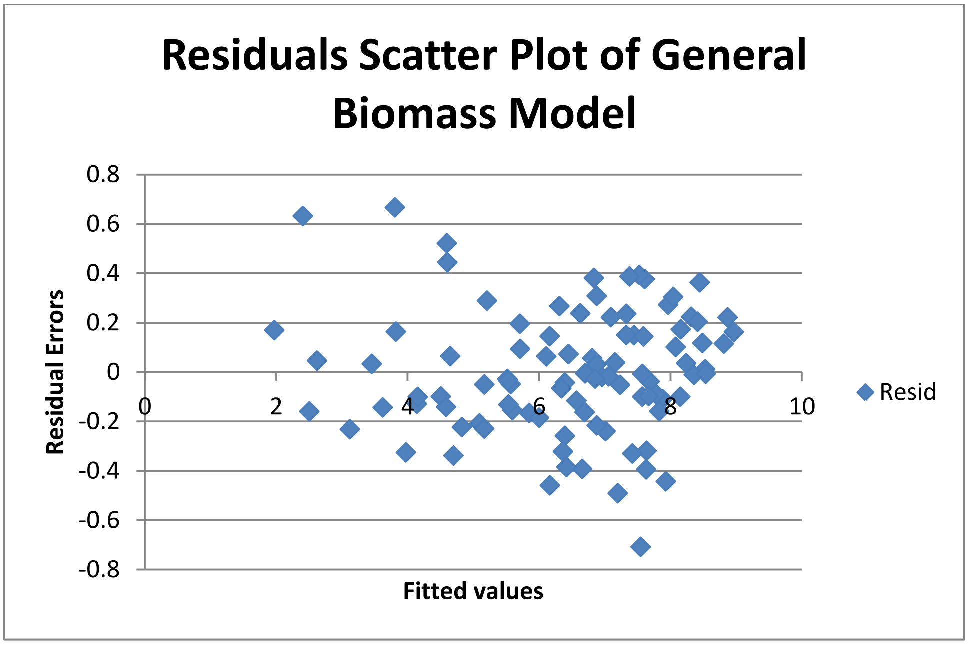

Figure 4. Residuals Scatter Plot for General Biomass Model for Coniferous Species

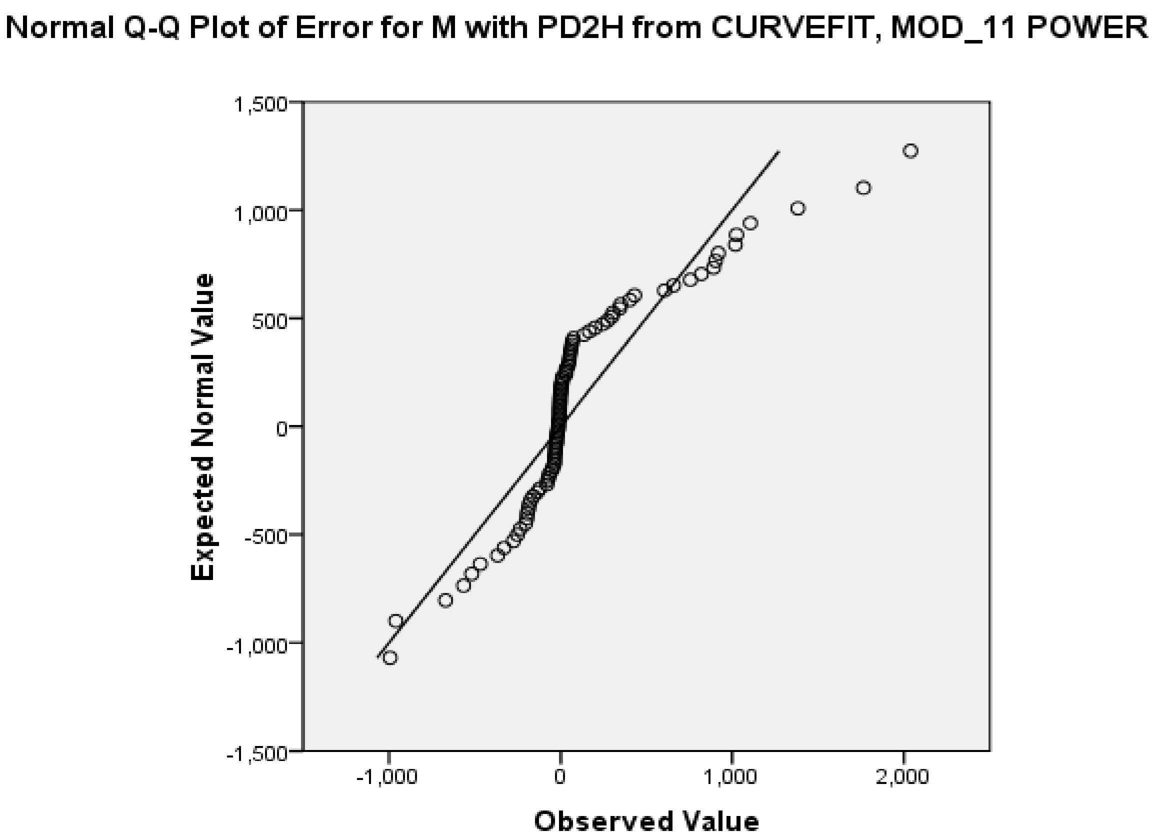

Figure 5. Q-Q Plot of Residual Errors of General Biomass Model

Biomass Tables

Biomass Tables were prepared on the basis of selected regression models. The dry biomass estimates were multiplied with 0.47 to obtain carbon stock as per IPCC default values (IPCC, 2006). Biomass and Carbon Tables are given from Biomass Table I to VI.

Basic Wood Density and Specific Gravity

Basic Wood Density is defined as the mass of a piece of dry wood per unit volume of green volume. It is measured in gram/cubic centimeter or Kg per cubic meter or tonnes per cubic meter. On the other hand, the specific gravity of wood is defined as the density of wood relative to the density of water which is 1.000 gram per cubic centimeter at 4.4 ° C; therefore, specific gravity is unitless. The specific gravity of wood depends on the relative proportions of cellulose, lignin, hemicellulose, extraneous components, gas, and water (moisture content or MC). Because the MC of wood can vary greatly, specific gravity is measured on the basis of oven dry (101 – 105 ° C) mass of the wood (Williamson and Wiemann, 2010). Basic wood density or specific gravity is required to covert volume estimates into dry biomass. The basic wood densities and specific gravities of the selected species are given in the following table.

Table 3. Basic Wood Densities and Specific Gravities of different tree species

Species	BWD (g/cm3)	BWD (Kg/m3)	Specific Gravity
Cedrus deodara	460	460	0.46
Pinus wallichiana	430	430	0.43
Pinus gerardiana	500	500	0.50
Abies pindrow	420	420	0.42
Picea smithiana	430	430	0.43
Quercus ilex	890	890	0.890

Biomass Expansion Factors (BEF)

BEF is a factor that expands the dry-weight of bole biomass to account for non-merchantable or non-commercial biomass components, such as branches, twigs and foliage. BEFs and basic wood density are used to convert the wood volume estimates into above ground total biomass. BEFs vary from species to species and growing conditions. BEFs were determined for deodar, kail, fir, spruce and oak of Gilgit Baltistan which are given in the following table.

Species	Bole Dry Weight %	Branch Dry Weight %	Brushwood Dry weight %	BEF
Cedrus deodara	72.95	10.43	16.62	1.37
Pinus wallichiana	80.62	9.11	10.27	1.24
Abies pindrow	77	10	13	1.30
Picea smithiana	84.11	6.5	9.39	1.19
Quercus ilex	59.82	27.32	12.86	1.67

BIOMASS TABLE I

Biomass and Carbon Table of *Cedrus deodara* (Deodar)

DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg	DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg
6	4.50	10.98	5.16	54	26.85685	1643.072	772.2439
8	5.00	19.06	8.96	56	27.41528	1772.127	832.8998
10	6.00	31.72	14.91	58	27.9541	1905.646	895.6535
12	6.50	45.48	21.37	60	28.47466	2043.599	960.4914
14	7.00	62.00	29.14	62	28.97815	2185.958	1027.4
16	8.18	87.32	41.04	64	29.46565	2332.695	1096.367
18	9.99	124.26	58.40	66	29.93815	2483.785	1167.379
20	11.61	166.46	78.24	68	30.39654	2639.2	1240.424
22	13.07	213.89	100.53	70	30.84164	2798.917	1315.491
24	14.41	266.50	125.25	72	31.27421	2962.91	1392.568
26	15.63	324.22	152.38	74	31.69492	3131.157	1471.644
28	16.77	387.01	181.89	76	32.10441	3303.633	1552.708
30	17.83	454.81	213.76	78	32.50326	3480.318	1635.749
32	18.82	527.58	247.96	80	32.89202	3661.188	1720.758
34	19.75	605.27	284.48	82	33.27117	3846.223	1807.725
36	20.63	687.82	323.28	84	33.64119	4035.402	1896.639
38	21.46	775.20	364.34	86	34.0025	4228.705	1987.491
40	22.25	867.35	407.66	88	34.35551	4426.112	2080.273
42	23.00	964.25	453.20	90	34.70058	4627.604	2174.974
44	23.71	1065.85	500.95	92	35.03806	4833.162	2271.586
46	24.39	1172.11	550.89	94	35.36829	5042.767	2370.101
48	25.05	1283.00	603.01	96	35.69157	5256.403	2470.509
50	25.68	1398.47	657.28	98	36.00818	5474.05	2572.803
52	26.28	1518.51	713.70	100	36.31839	5695.692	2676.975

Derived from the equations:

$M = 0.1779(D^2H)^{0.8103}$ or $M = \exp\{-1.7264+0.8103Ln(D2H)\}$

$H = -34.394+15.355\ln D$

Where M is the dry biomass in Kg, D is DBH in cm, H is tree height in m, Ln is the natural log

Carbon Stock = 0.47xM

BIOMASS TABLE II

Biomass and Carbon Table of *Pinus wallichiana* (Kail)

DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg	DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg
6	5.00	6.08	2.86	54	29.42	1381.88	649.48
8	5.00	10.09	4.74	56	29.95	1496.34	703.28
10	6.00	17.55	8.25	58	30.45	1615.34	759.21
12	7.68	30.05	14.12	60	30.94	1738.89	817.28
14	9.91	49.31	23.18	62	31.42	1866.97	877.48
16	11.84	72.95	34.29	64	31.88	1999.59	939.81
18	13.54	101.01	47.48	66	32.32	2136.74	1004.27
20	15.06	133.55	62.77	68	32.75	2278.41	1070.85
22	16.44	170.57	80.17	70	33.17	2424.61	1139.57
24	17.70	212.12	99.69	72	33.58	2575.32	1210.40
26	18.86	258.19	121.35	74	33.98	2730.55	1283.36
28	19.93	308.81	145.14	76	34.36	2890.28	1358.43
30	20.92	363.97	171.07	78	34.74	3054.52	1435.63
32	21.86	423.70	199.14	80	35.10	3223.26	1514.93
34	22.73	487.99	229.35	82	35.46	3396.50	1596.35
36	23.56	556.84	261.71	84	35.81	3574.22	1679.88
38	24.34	630.25	296.22	86	36.15	3756.43	1765.52
40	25.08	708.24	332.87	88	36.48	3943.13	1853.27
42	25.79	790.79	371.67	90	36.81	4134.30	1943.12
44	26.46	877.90	412.61	92	37.12	4329.94	2035.07
46	27.10	969.58	455.70	94	37.43	4530.05	2129.13
48	27.72	1065.82	500.94	96	37.74	4734.63	2225.28
50	28.31	1166.62	548.31	98	38.04	4943.67	2323.52
52	28.88	1271.97	597.83	100	38.33	5157.16	2423.86

Derived from the equations:

$M= 0.0631(D^2H)^{0.8798}$ or $M = \exp\{- 2.7638+0.8798Ln(D2H)\}$

$H= - 28.244+14.456\ln D$

Where M is the dry biomass in Kg, D is DBH in cm, H is tree height in m, Ln is the natural log

Carbon Stock = 0.47xM

BIOMASS TABLE III

Biomass and Carbon Table of *Abies pindrow* (Fir)

DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg	DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg
6	6.03	7.51	3.53	54	27.40725	906.9033	426.2445
8	8.83	16.32	7.67	56	27.761	972.1004	456.8872
10	11.00	28.02	13.17	58	28.10234	1039.319	488.48
12	12.78	42.52	19.98	60	28.4321	1108.544	521.0155
14	14.28	59.75	28.08	62	28.75105	1179.759	554.4866
16	15.58	79.64	37.43	64	29.05987	1252.95	588.8865
18	16.72	102.13	48.00	66	29.35919	1328.103	624.2085
20	17.75	127.17	59.77	68	29.64957	1405.205	660.4462
22	18.67	154.70	72.71	70	29.93154	1484.242	697.5935
24	19.52	184.69	86.80	72	30.20556	1565.201	735.6443
26	20.30	217.09	102.03	74	30.47207	1648.07	774.5929
28	21.02	251.86	118.37	76	30.73148	1732.838	814.4337
30	21.69	288.97	135.82	78	30.98414	1819.492	855.1611
32	22.32	328.40	154.35	80	31.23041	1908.021	896.7699
34	22.91	370.10	173.95	82	31.4706	1998.415	939.2549
36	23.46	414.05	194.60	84	31.705	2090.662	982.6112
38	23.99	460.22	216.30	86	31.93388	2184.753	1026.834
40	24.49	508.59	239.04	88	32.1575	2280.677	1071.918
42	24.96	559.14	262.80	90	32.3761	2378.424	1117.859
44	25.42	611.84	287.56	92	32.58989	2477.985	1164.653
46	25.85	666.67	313.33	94	32.79908	2579.351	1212.295
48	26.26	723.61	340.10	96	33.00387	2682.512	1260.781
50	26.66	782.64	367.84	98	33.20444	2787.46	1310.106
52	27.04	843.74	396.56	100	33.40095	2894.185	1360.267

Derived from the equations:

$M = 0.0954(D^2H)^{0.8114}$ or $M = \exp\{-2.3495+0.8114 Ln(D2H)\}$

$H = -11.394+9.727 \ln D$

Where M is the dry biomass in Kg, D is DBH in cm, H is tree height in m, Ln is the natural log

Carbon Stock = 0.47Xm

BIOMASS TABLE IV

Biomass and Carbon Table of *Picea smithiana* (Spruce)

DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg	DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg
6	4	5.68	2.67	54	26.59	1170.11	549.95
8	5	11.17	5.25	56	27.05	1262.56	593.40
10	5.42	17.46	8.20	58	27.49	1358.38	638.44
12	7.71	32.05	15.06	60	27.91	1457.54	685.04
14	9.64	50.31	23.64	62	28.33	1560.04	733.22
16	11.32	72.26	33.96	64	28.72	1665.87	782.96
18	12.80	97.89	46.01	66	29.11	1775.01	834.25
20	14.12	127.19	59.78	68	29.48	1887.45	887.10
22	15.32	160.14	75.27	70	29.85	2003.18	941.50
24	16.41	196.74	92.47	72	30.20	2122.19	997.43
26	17.41	236.95	111.37	74	30.55	2244.47	1054.90
28	18.34	280.76	131.96	76	30.88	2370.00	1113.90
30	19.21	328.16	154.24	78	31.21	2498.78	1174.43
32	20.02	379.12	178.19	80	31.53	2630.80	1236.48
34	20.78	433.63	203.81	82	31.84	2766.04	1300.04
36	21.50	491.67	231.08	84	32.14	2904.50	1365.12
38	22.18	553.21	260.01	86	32.43	3046.17	1431.70
40	22.82	618.26	290.58	88	32.72	3191.03	1499.78
42	23.44	686.78	322.79	90	33.00	3339.08	1569.37
44	24.02	758.77	356.62	92	33.28	3490.31	1640.45
46	24.58	834.20	392.07	94	33.55	3644.71	1713.01
48	25.11	913.06	429.14	96	33.81	3802.27	1787.07
50	25.62	995.35	467.81	98	34.07	3962.98	1862.60
52	26.12	1081.03	508.09	100	34.33	4126.84	1939.61

Derived from the equations:

$M= 0.0843(D^2H)^{0.8472}$ or $M = \exp\{ - 2.4729+0.8472Ln(D2H)\}$

$H= - 23.491+12.555 \ln D$

Where M is the dry biomass in Kg, D is DBH in cm, H is tree height in m, Ln is the natural log

Carbon Stock = 0.47xM

BIOMASS TABLE V

Biomass and Carbon Table of of *Pinus gerardiana* (Chilghoza Pine)

DBH_cm	Dry Biomass_Kg	Carbon Stock_Kg	DBH_cm	Dry Biomass_Kg	Carbon Stock_Kg
6	2.71	1.27	54	833.07	391.54
8	5.73	2.69	56	915.95	430.50
10	10.25	4.82	58	1003.72	471.75
12	16.49	7.75	60	1096.49	515.35
14	24.65	11.59	62	1194.37	561.36
16	34.92	16.41	64	1297.47	609.81
18	47.48	22.31	66	1405.87	660.76
20	62.49	29.37	68	1519.69	714.25
22	80.12	37.66	70	1639.01	770.34
24	100.53	47.25	72	1763.95	829.06
26	123.86	58.22	74	1894.59	890.46
28	150.27	70.63	76	2031.04	954.59
30	179.89	84.55	78	2173.38	1021.49
32	212.86	100.05	80	2321.71	1091.20
34	249.32	117.18	82	2476.13	1163.78
36	289.39	136.02	84	2636.72	1239.26
38	333.21	156.61	86	2803.57	1317.68
40	380.90	179.02	88	2976.79	1399.09
42	432.58	203.31	90	3156.45	1483.53
44	488.37	229.54	92	3342.64	1571.04
46	548.40	257.75	94	3535.46	1661.67
48	612.76	288.00	96	3734.99	1755.44
50	681.59	320.35	98	3941.31	1852.42
52	754.99	354.85	100	4154.52	1952.62

Derived from the equations:

$M = 0.0253D^{2.6077}$ or $M = \exp\{ -3.6764+ 2.6077 \mathrm{Ln} D\}$

Where M is the dry biomass in Kg and D is DBH in cm, Ln is the natural log

Carbon Stock = 0.47xM

BIOMASS TABLE VI
Biomass and Carbon Table of *Quercus ilex* (Oak)

DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg	DBH_cm	Height_m	Dry Biomass_Kg	C stock_Kg
6	3.51	20.74	9.75	54	10.34	794.01	373.19
8	3.79	32.04	15.06	56	10.63	848.61	398.85
10	4.08	45.25	21.27	58	10.91	904.99	425.35
12	4.36	60.33	28.36	60	11.20	963.15	452.68
14	4.65	77.26	36.31	62	11.48	1023.10	480.86
16	4.93	96.02	45.13	64	11.77	1084.82	509.87
18	5.22	116.60	54.80	66	12.05	1148.33	539.71
20	5.50	138.99	65.33	68	12.34	1213.61	570.40
22	5.79	163.19	76.70	70	12.62	1280.68	601.92
24	6.07	189.19	88.92	72	12.91	1349.52	634.27
26	6.36	216.99	101.98	74	13.19	1420.14	667.47
28	6.64	246.58	115.89	76	13.48	1492.55	701.50
30	6.93	277.96	130.64	78	13.76	1566.73	736.36
32	7.21	311.14	146.24	80	14.05	1642.69	772.07
34	7.49	346.11	162.67	82	14.33	1720.43	808.60
36	7.78	382.86	179.95	84	14.61	1799.95	845.98
38	8.06	421.41	198.06	86	14.90	1881.25	884.19
40	8.35	461.74	217.02	88	15.18	1964.33	923.23
42	8.63	503.85	236.81	90	15.47	2049.18	963.11
44	8.92	547.75	257.44	92	15.75	2135.81	1003.83
46	9.20	593.44	278.92	94	16.04	2224.22	1045.38
48	9.49	640.91	301.23	96	16.32	2314.41	1087.77
50	9.77	690.16	324.37	98	16.61	2406.38	1131.00
52	10.06	741.19	348.36	100	16.89	2500.12	1175.06

Derived from the equations:

$M= 0.8277(D^2H)^{0.6655}$ or $M = \exp\{- 0.1891+0.6657Ln(D2H)\}$

$H= 0.1424D + 2.6532$

Where M is the dry biomass in Kg, D is DBH in cm, H is tree height in m, Ln is the natural log

Carbon Stock = 0.47xM

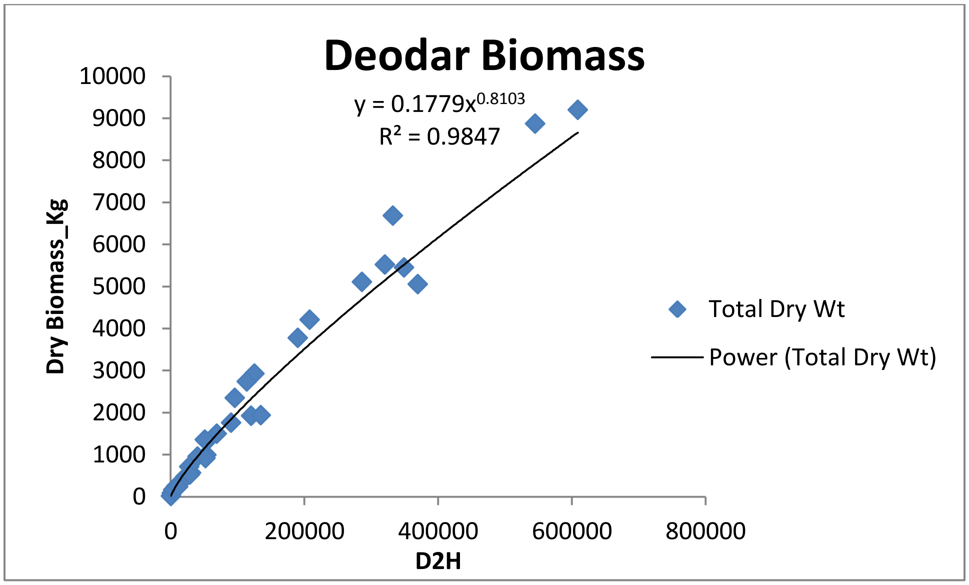

Figure 6. Deodar Biomass Model

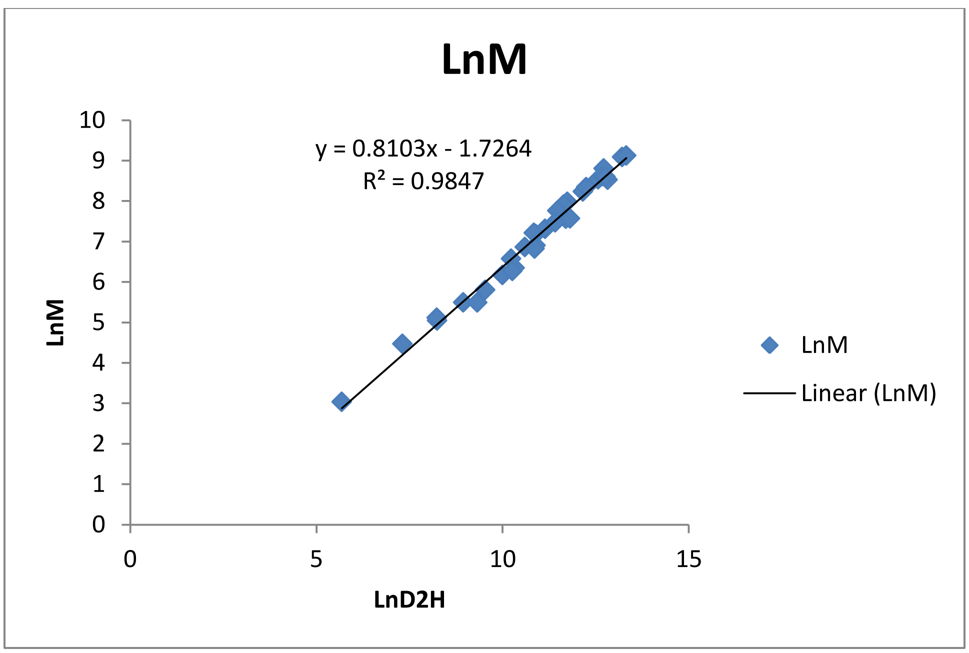

Figure 7. Deodar Biomass Model (Log Transformed)

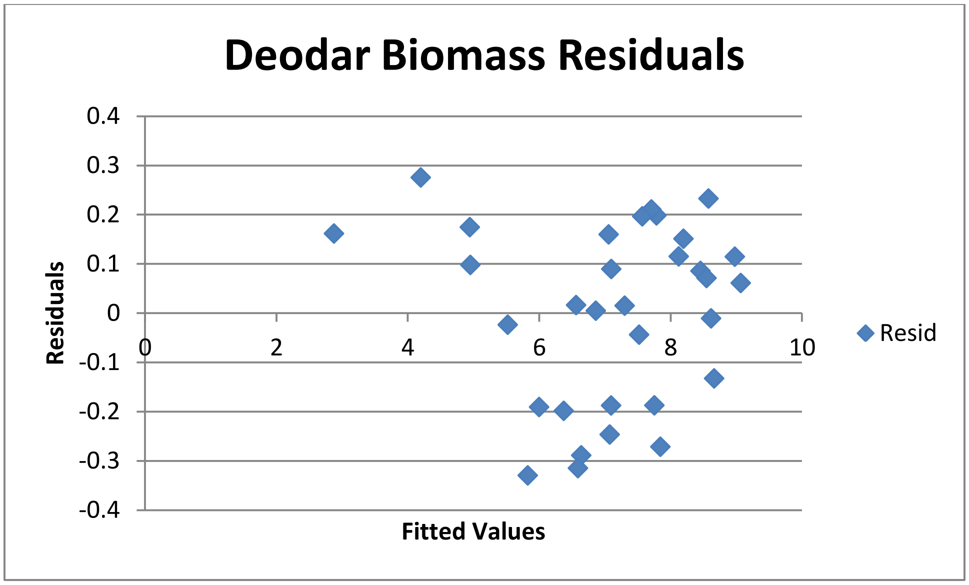

Figure 8. Scatter Plot of Deodar Biomass residuals

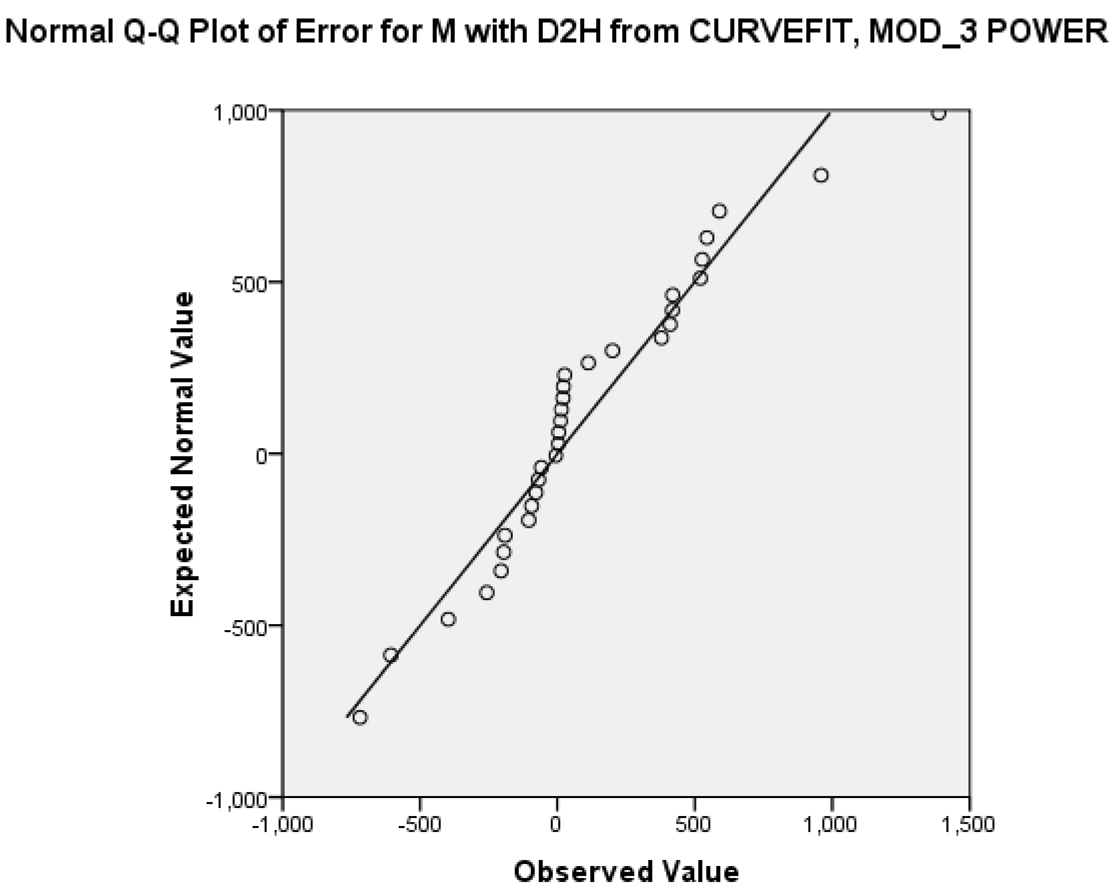

Figure 9: Q-Q Plot of Deodar Biomass

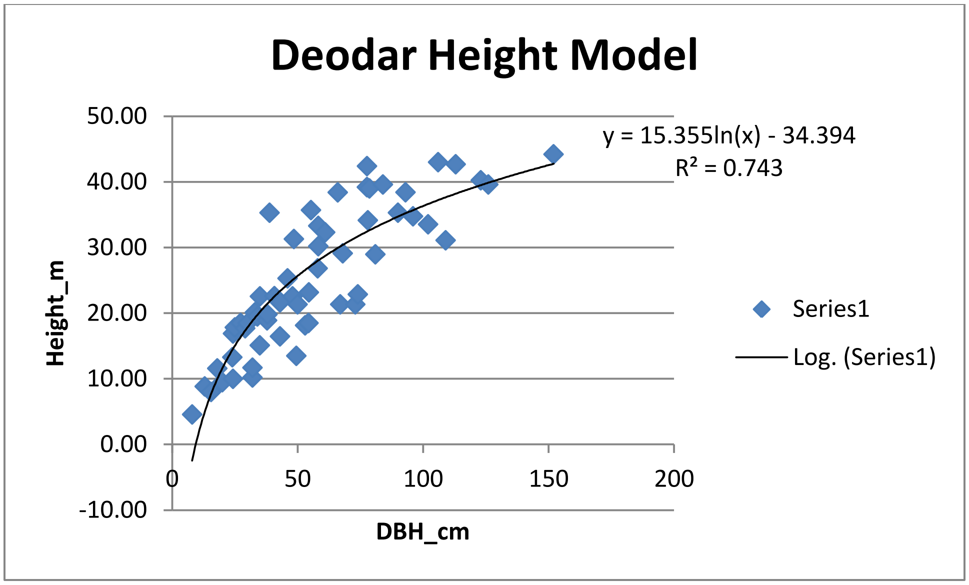

Figure 10. Deodar Height Model

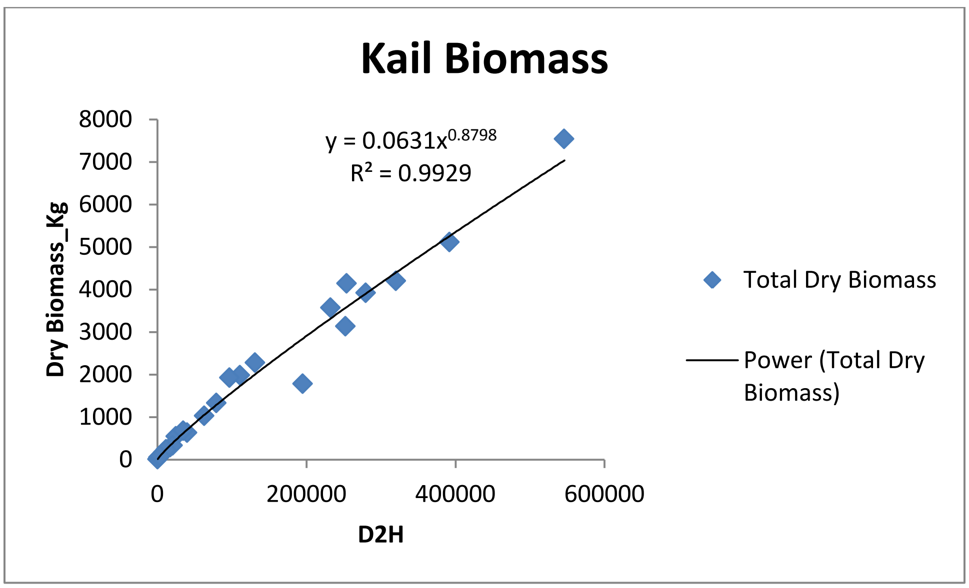

Figure 11. Kail Biomass Model

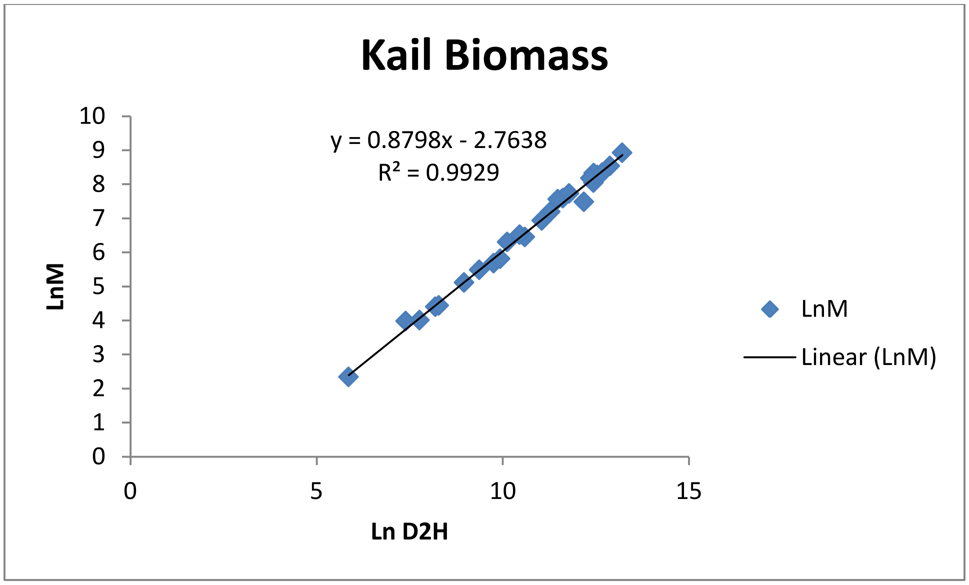

Figure 12. Kail Biomass Model (Log Transformed)

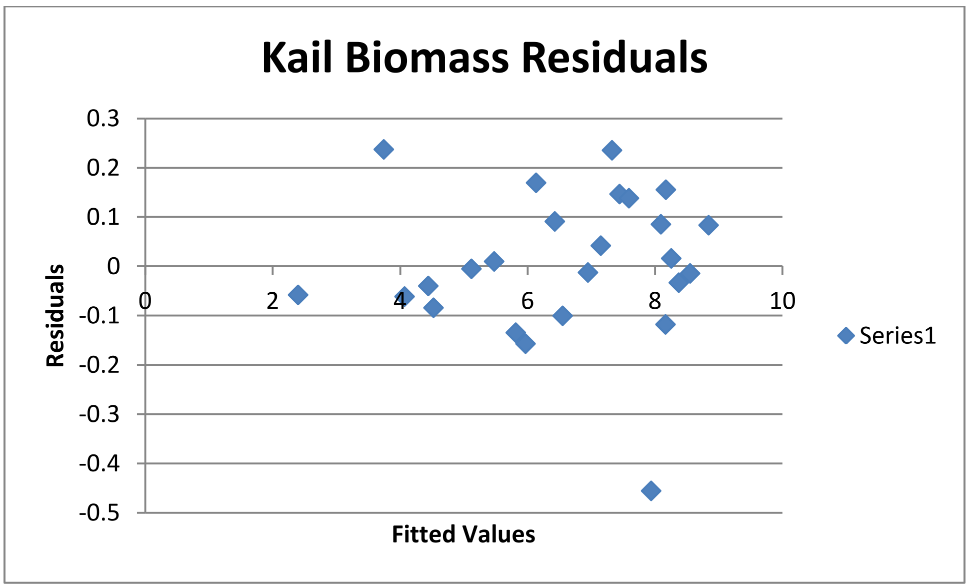

Figure 13. Scatter Plot of Kail Biomass residuals

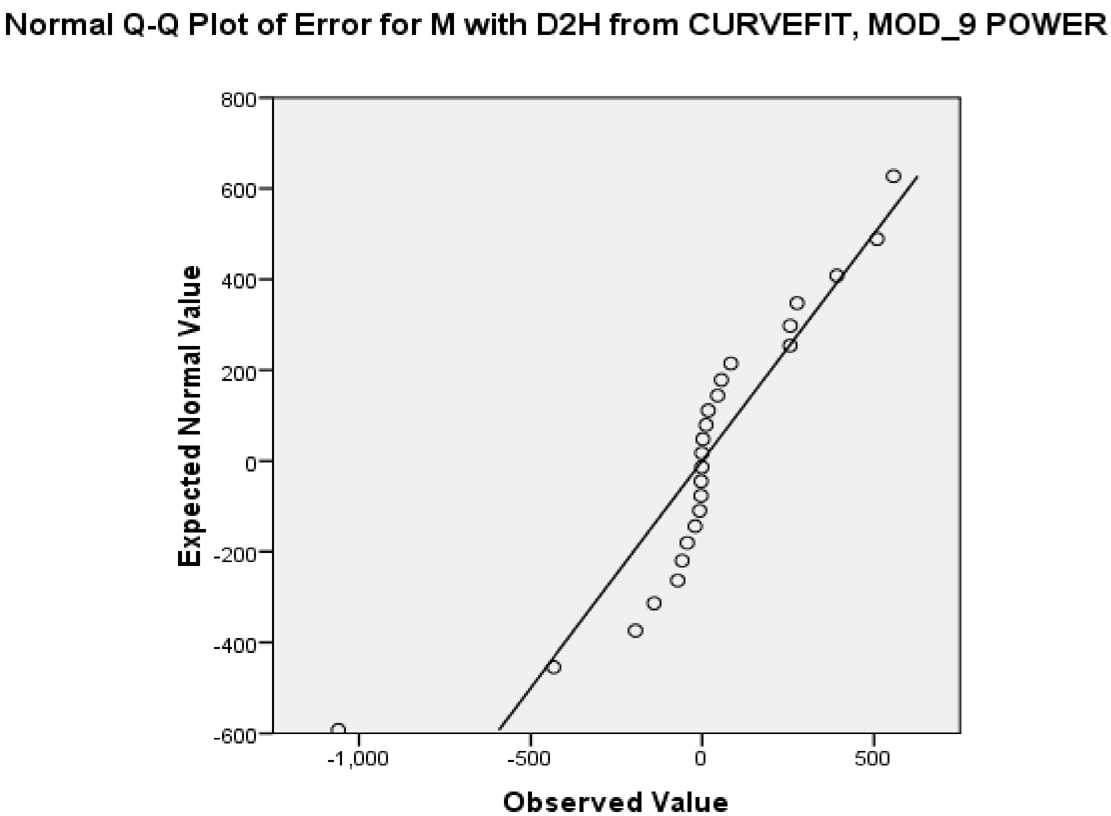

Figure 14. Q-Q Plot of Kail Biomass Residual Errors

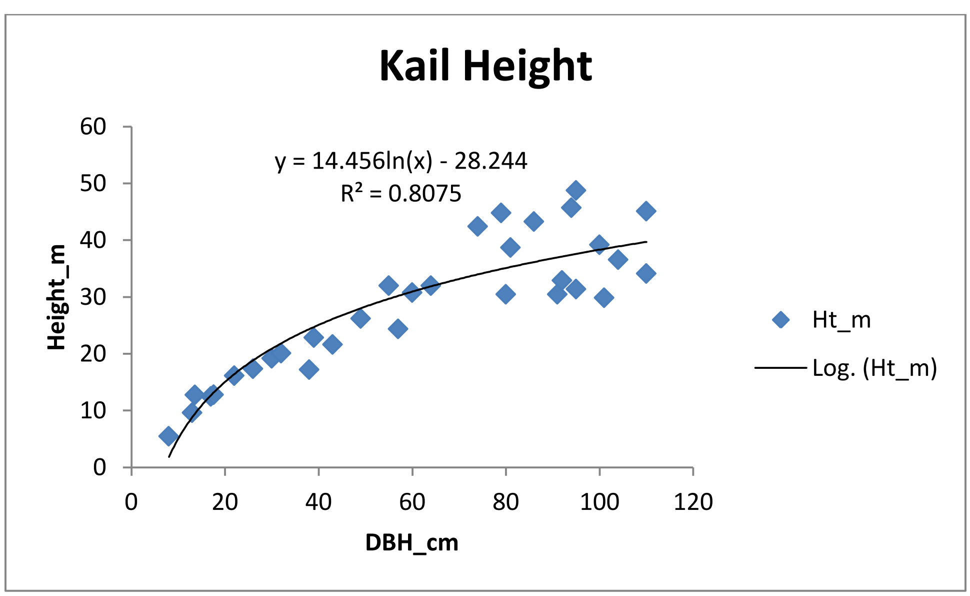

Figure 15. Kail Height Model

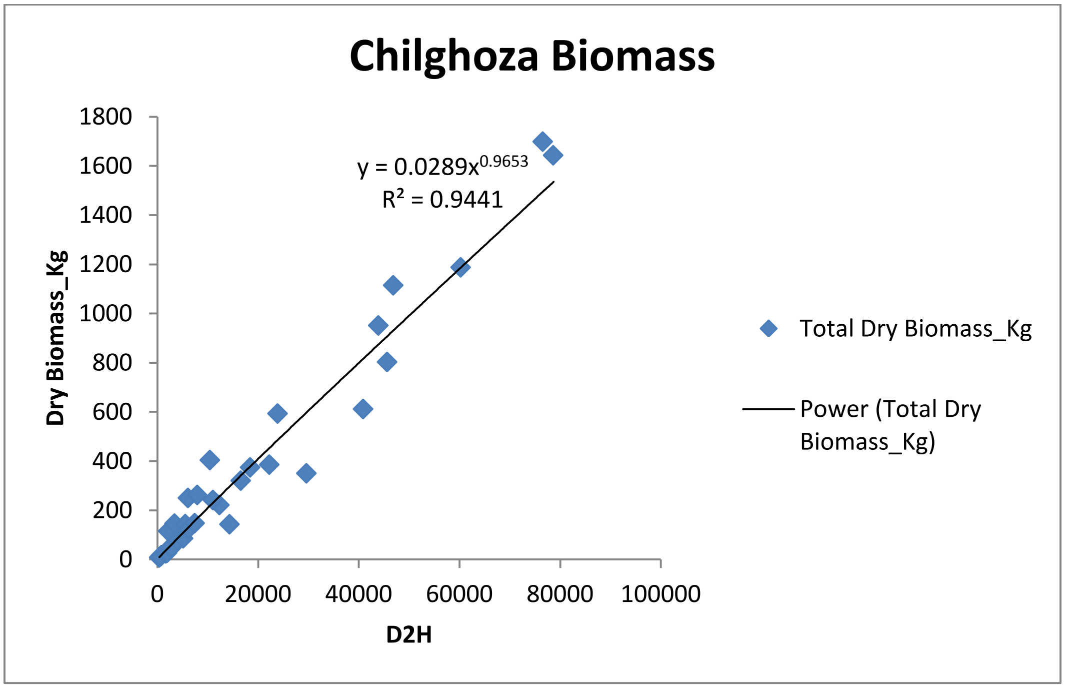

Fig. 16 Biomass Model of Chilghoza Pine based on diameter and height

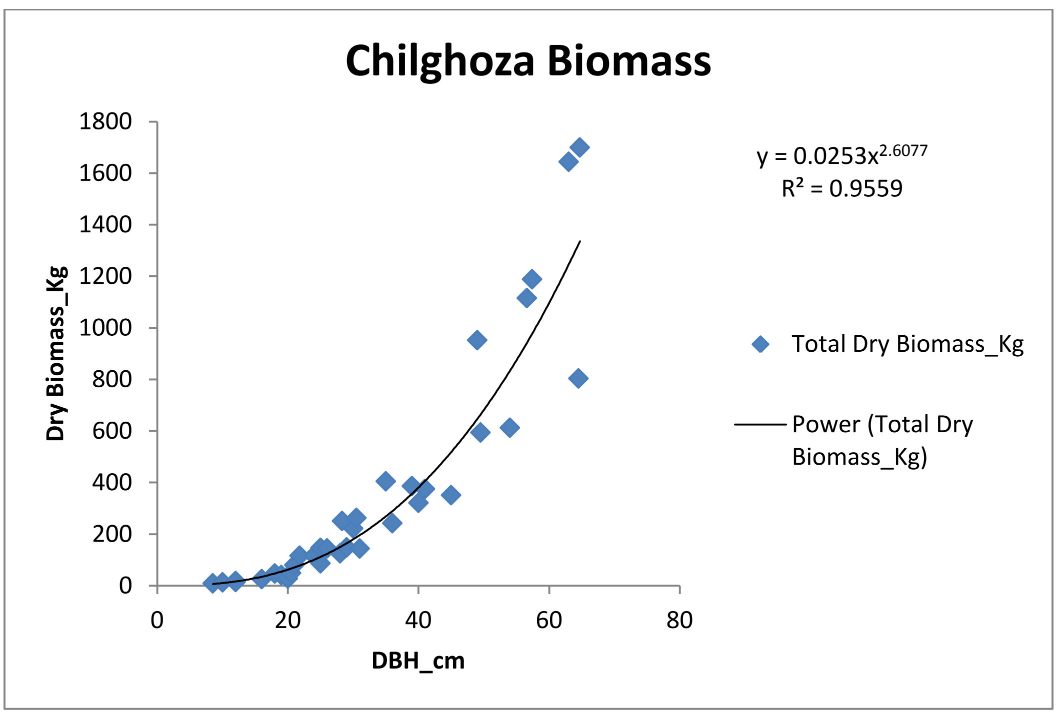

Fig. 17 Biomass Model of Chilghoza Pine based on diameter

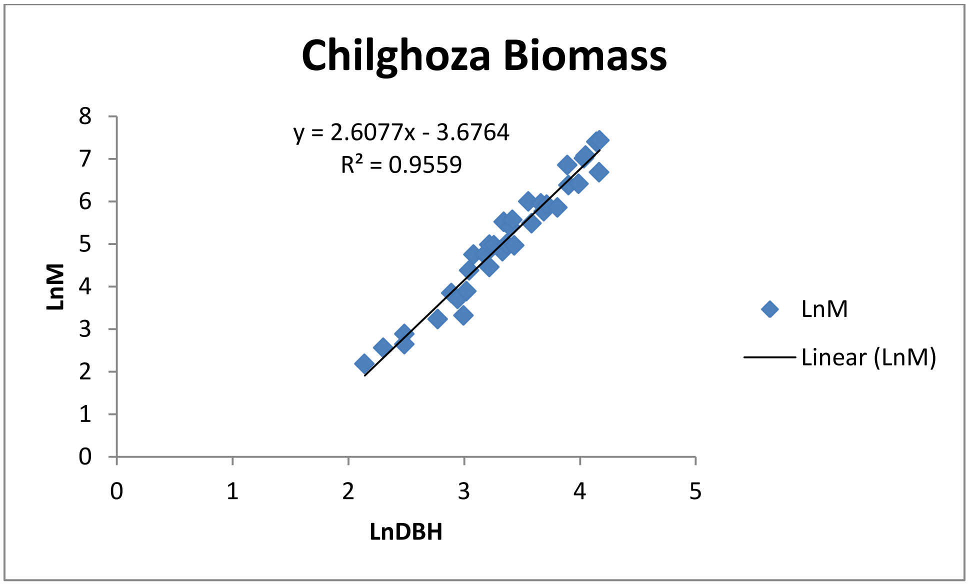

Fig. 18 Biomass Model of Chilghoza Pine based on log transformed data

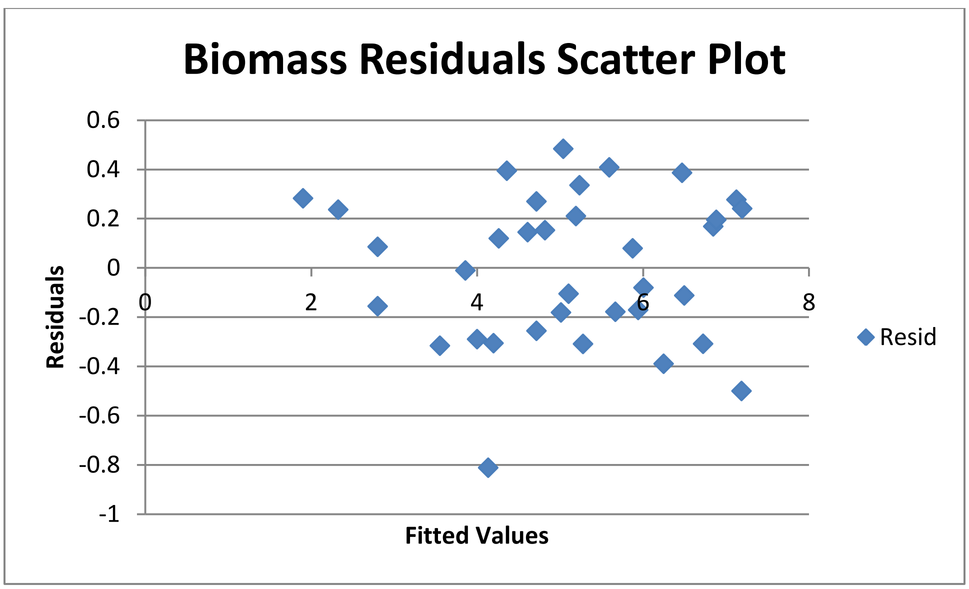

Fig.19 Residual scatter plot of Biomass Model of Chilghoza Pine

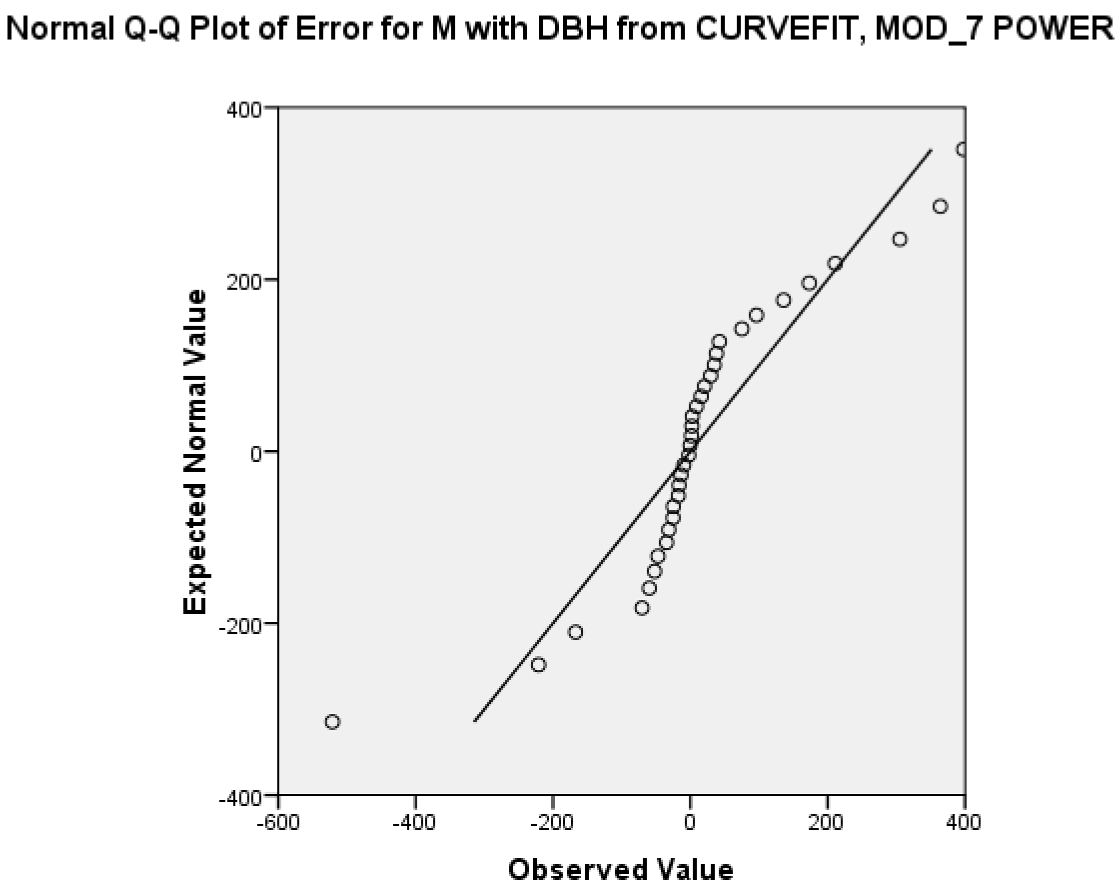

Fig.20 Q-Q Plot of Chilghoza Biomass Residuals

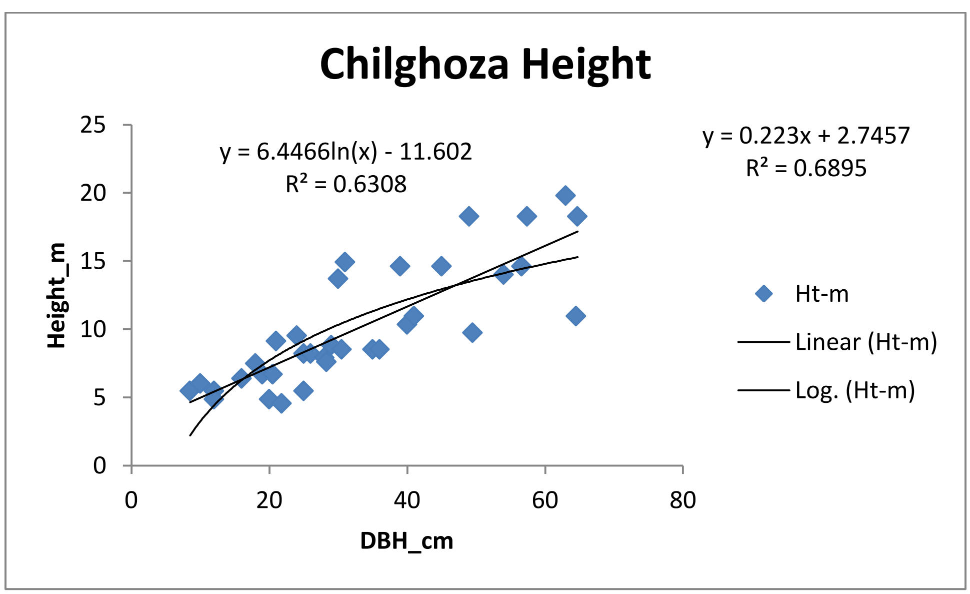

Fig. 21 Chilghoza Height Model

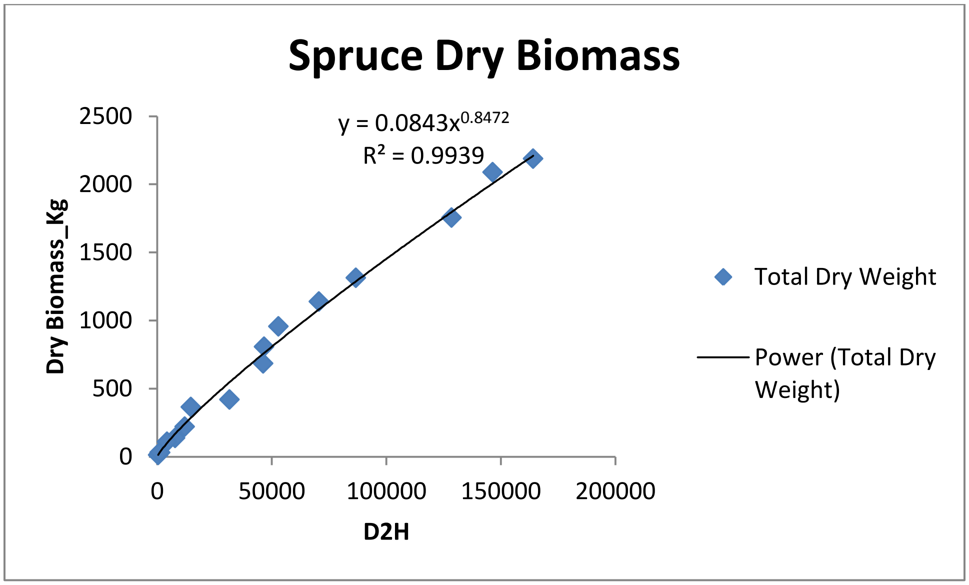

Fig. 22 Spruce Biomass Model

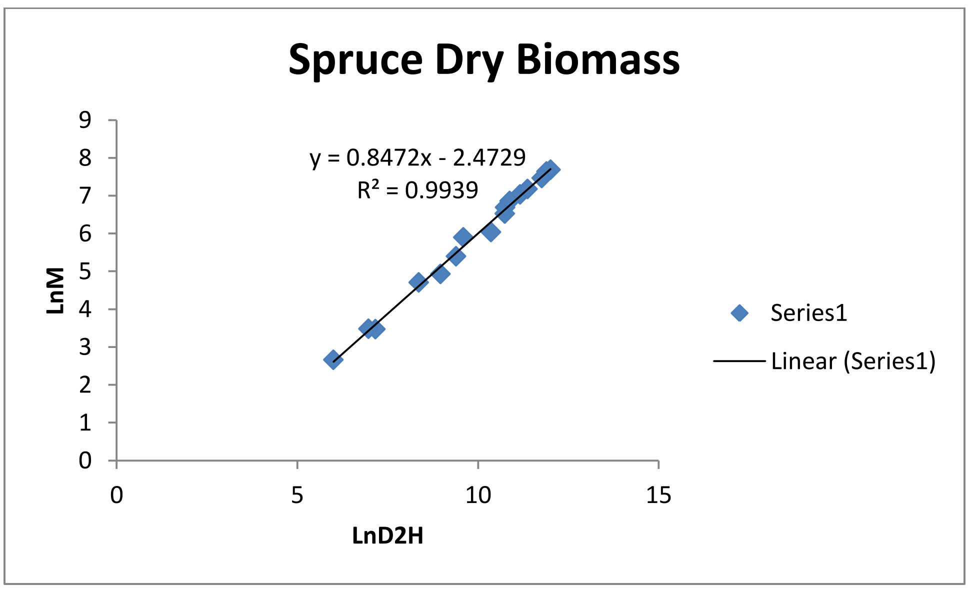

Fig. 23 Spruce Biomass Model (Log Transformed)

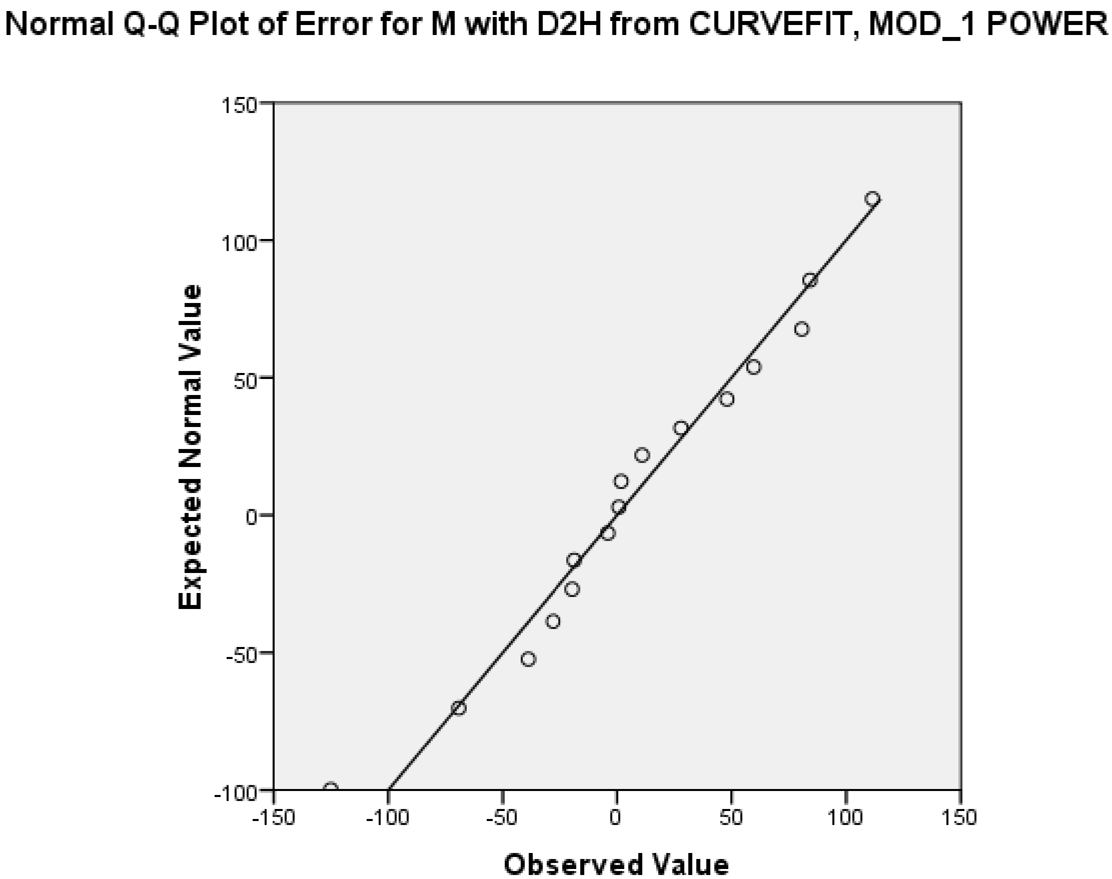

Figure 24. Q-Q Plot of Residual Errors of Spruce Biomass Model

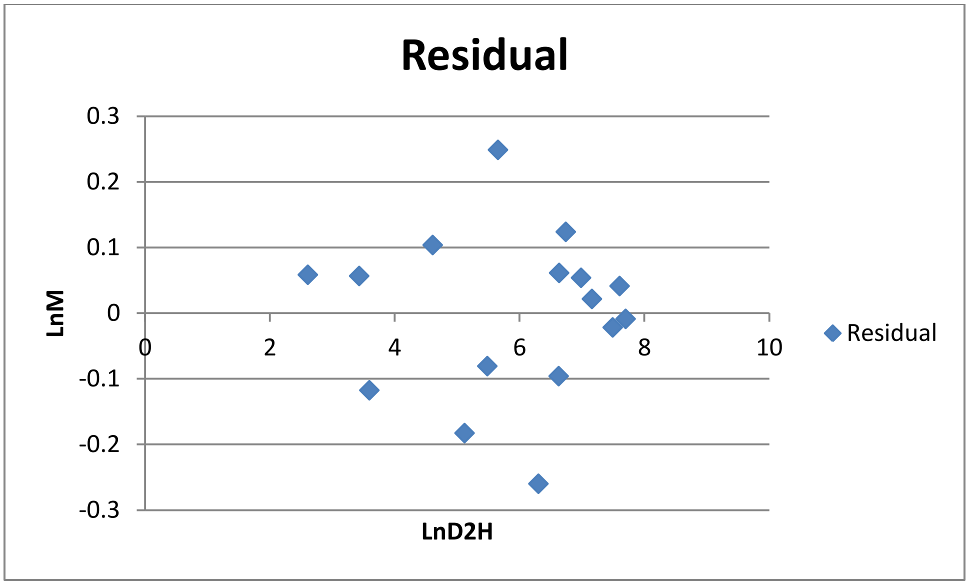

Fig. 25 Residual scatter plot of Biomass Model of Spruce

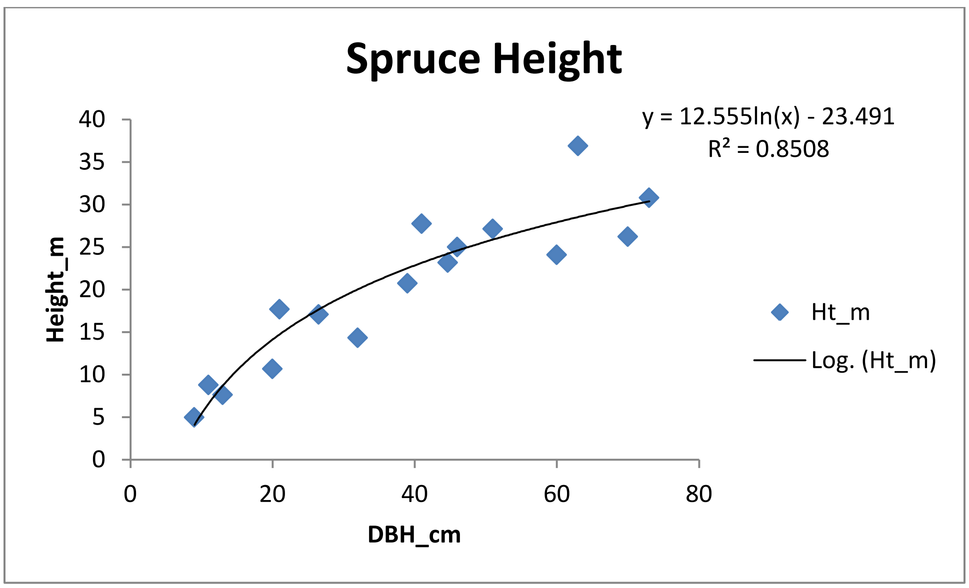

Figure 26. Spruce Height Model

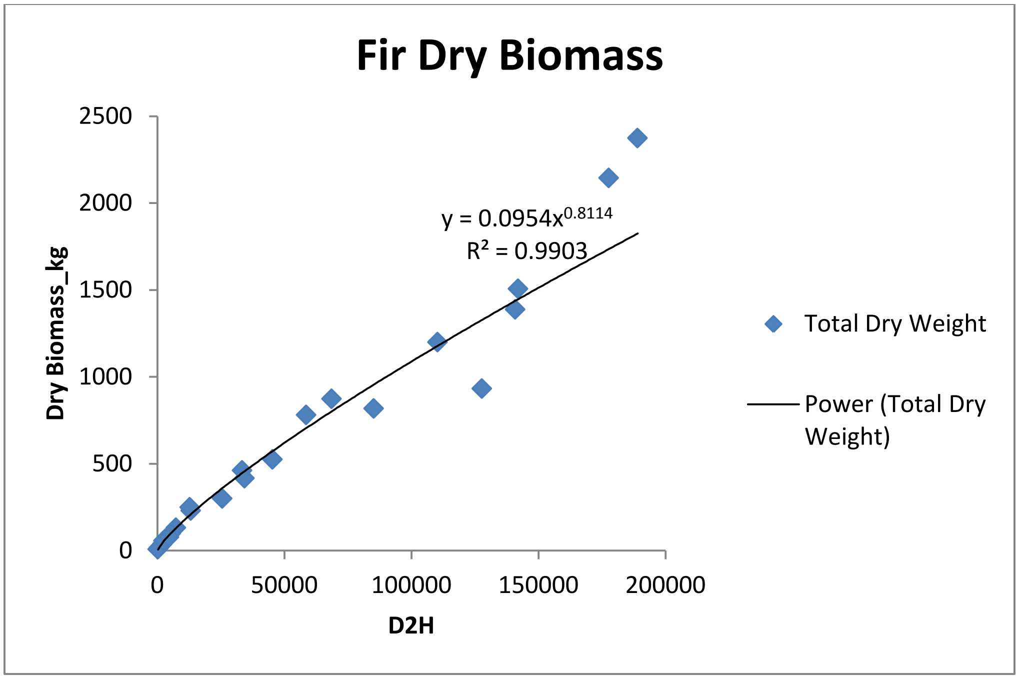

Figure 27. Fir Biomass Model

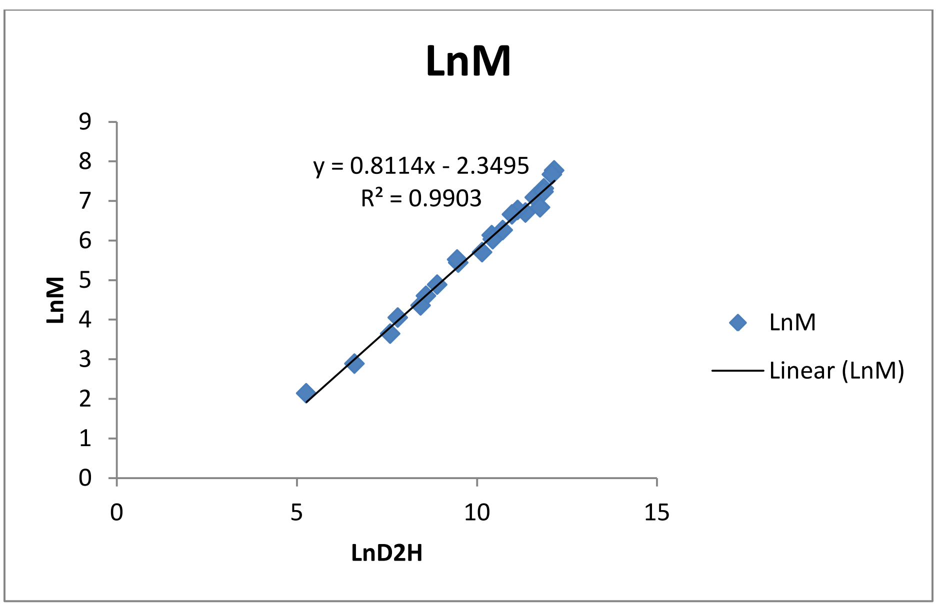

Figure 28. Fir Biomass Model (Log Transformed)

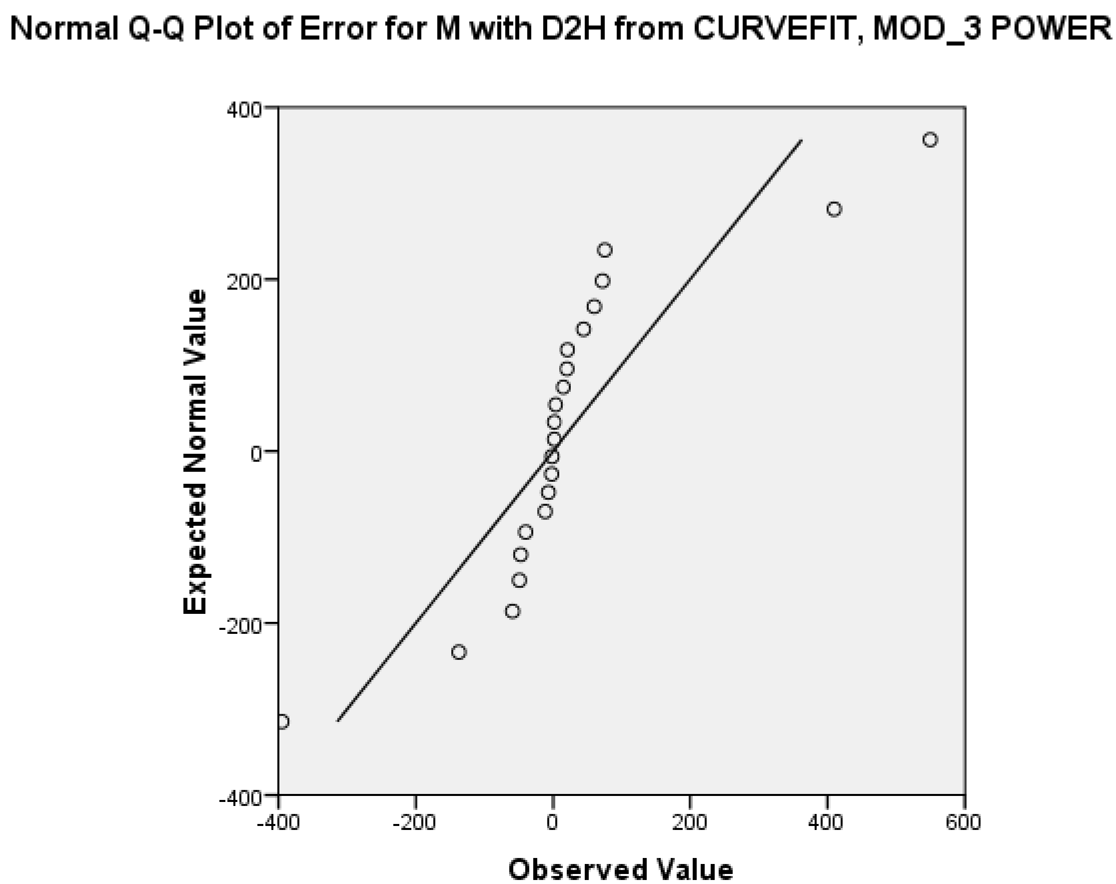

Fig. 29 Q-Q Plot of Fir Biomass Residuals

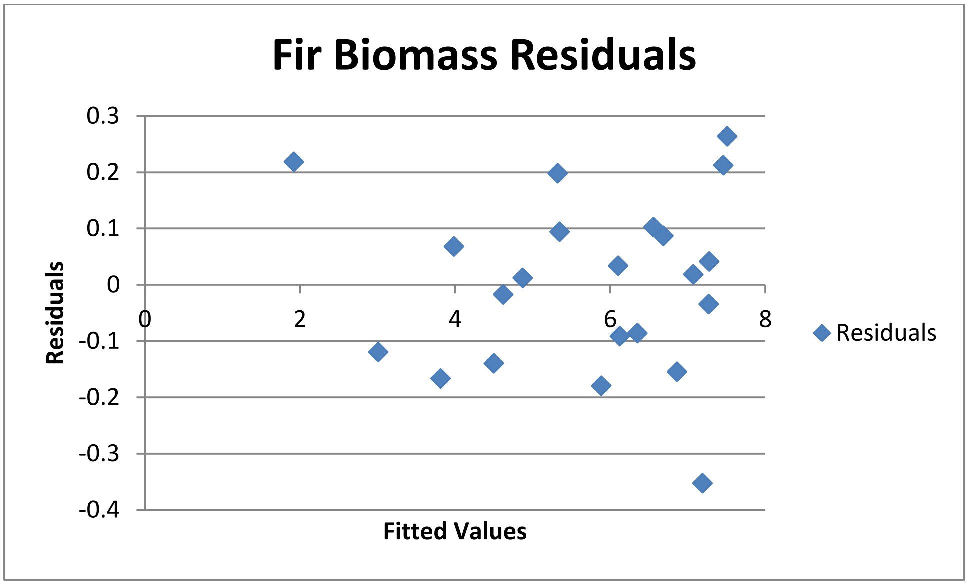

Fig. 30 Residual scatter plot of Biomass Model of Fir

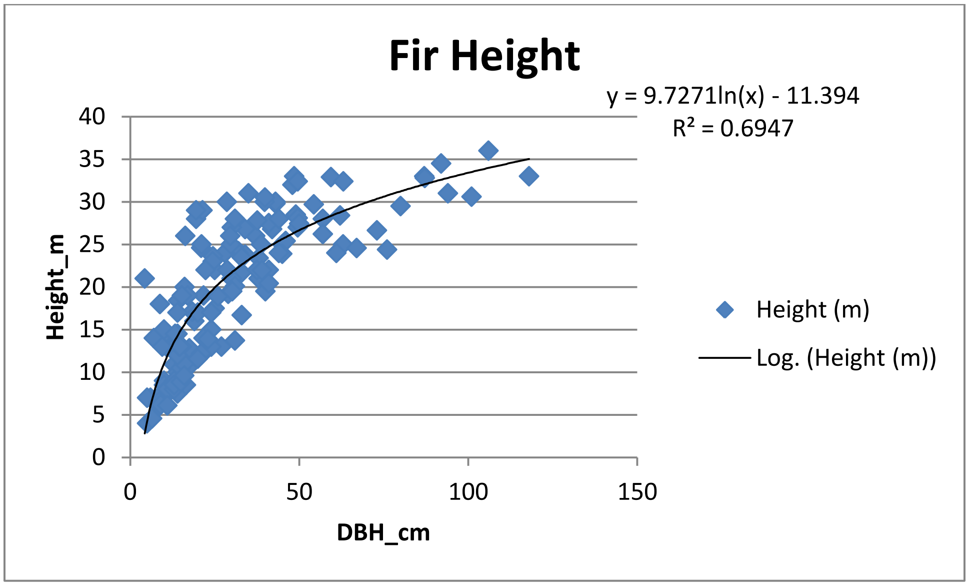

Fig. 31 Fir Height Model

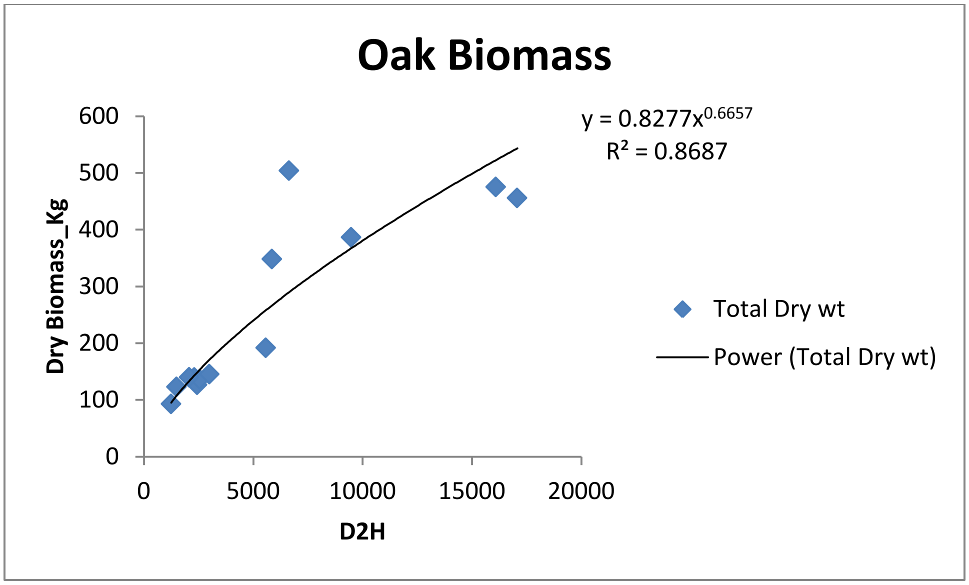

Figure 31. Oak Biomass Model

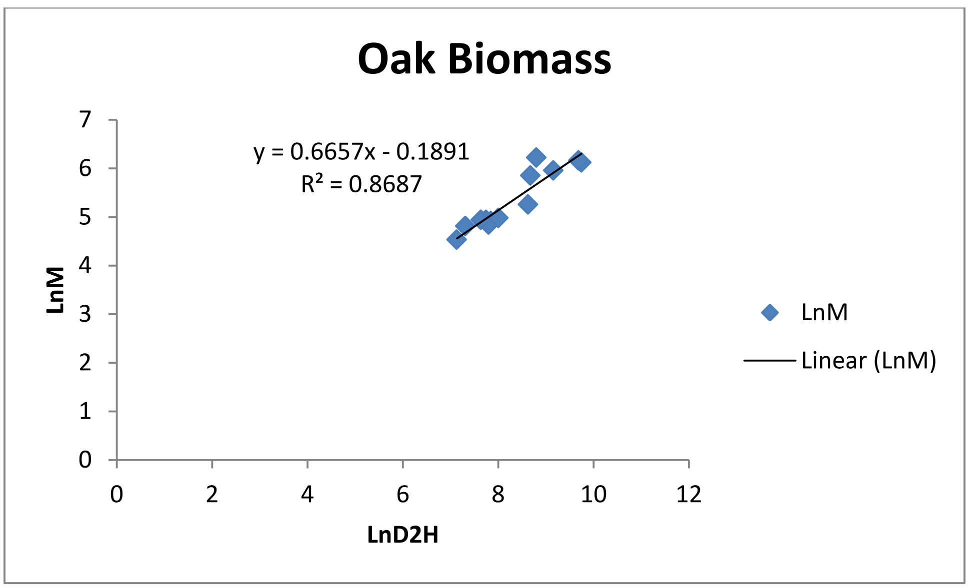

Figure 32. Oak Biomass Model (Log Transformed)

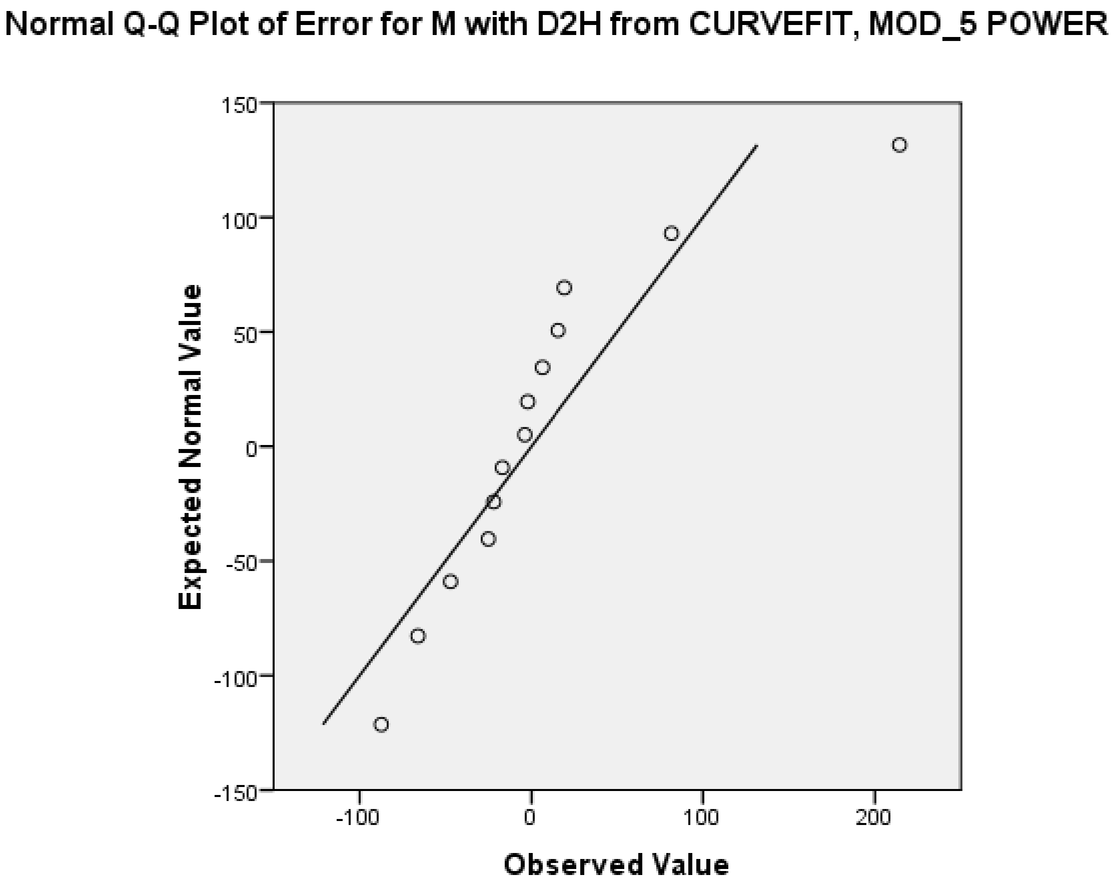

Figure 33. Q-Q Plot of Residual Errors of Oak Biomass

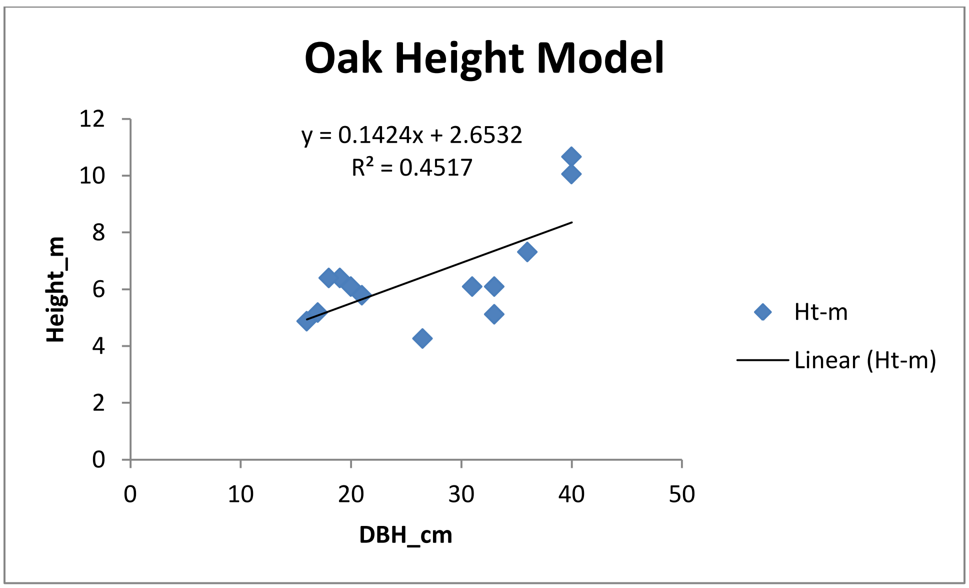

Figure 34. Oak Height Model

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ANNEX-I

DATA COLLECTION FORM FOR PREPARATION OF BIOMASS TABLE

Species________________________________Locality____

X-Coordinate___________________________Y-Coordinate____________________________________

Elevation________________Stand Density_________________Aspect__________________________

Tree No____________DBH (cm)______________Height (m)______________Age__________________

Clear Bole (height)_____________Crown length___________________Crown Width______________

Timber Data (logs upto 20 cm dia at thin end**)**

Piece No	Dia (cm)			Length (m)	Weight (kg)
	Thick end	Mid	Thin end		

Smallwood (logs from stem or branches with dia 20 cm at thick end and 5 cm at thin end)

Piece No	Dia (cm)			Length (m)	Weight (kg)
	Thick end	Mid	Thin end		

Discs Data

Disc No	Dia (cm)	Length (cm)	Fresh weight (gm)	Oven Dry weight (gm)

Brushwood Data

	Total Fresh weight (kg)	Sample weight (gm)	Oven Dry weight of samples (gm)
Branches (less than 5 cm dia)			
Leaves			

ANNEX II
DATA COLLECTION FORM FOR MC AND WOOD DENSITY

Biomass Data Species______________________________Date____________________________

Tree No.	Disc No.	Diameter (cm)	Av. Length (cm)	Volume (cm^3)	Fresh wt (gm)	OB Oven dry wt (gm)	UB Oven dry wt (gm)	Moisture (%)	Density (g/cm^3)	Bark fresh wt	Bark Oven Dry wt	Branch Fresh wt	Branch Dry wt	Leaves fresh wt	Leaves oven dry wt