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Variation in Wood Specific Gravity, Density and Moisture Content of *Dipterocarpus indicus* (Bedd). among Different Populations in Western Ghats of Karnataka, India

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Abstract

Twenty four core samples were extracted from *Dipterocarpus indicus* having a girth of 120 – 140 cm gbh (at breast height) in eight populations. The variations in specific gravity, density and moisture content were evaluated among populations for utilization and tree improvement programme. Shrinkage, moisture content based on dry condition (MCD), moisture content based on green condition (MCG), maximum moisture content (MMC), sink moisture content (SMC), shrinkage volumetric (SV) and equilibrium moisture content (EMC) were investigated. The variations among different populations were significant for all physical wood properties. Specific gravity (SG), density (D) and moisture content (MC) were found to be derived by environmental factors. Based on SG, Wood of *Dipterocarpus indicus* classified into moderately heavy and heavy wood quality. SG was negatively correlated with geoclimatic factors (Latitude, altitude, rainfall and temperature) and moisture content components (MCD, MCG, MMC, MS, SV and shrinkage).

Keywords: Density; *Dipterocarpus indicus*; moisture content; specific gravity, Western Ghats; Wood density.

Introduction

Dipterocarpus indicus is a timber tree species endemic to the Southern Western Ghats of India, particularly in the tropical lowland forest areas in Karnataka, Kerala and Tamil Nadu. In Karnataka the species are abundant in the wet evergreen forest of

Kodagu, Hassan, Uttara Kannada, Dakshina Kannada, Chikkamagalore. It is excellent plywood and widely used for construction purposes. It is also a good fuel wood which has calorific value of 5199 k cal/kg [1]. As the demand for wood and paper products increases, ensuring the wood supply for the future becomes increasingly important. Therefore, the efficient utilization of timber is not possible without knowledge of the anatomical structure of wood. For a proper understanding of the anatomical structure of wood and its bearing on timber utilization, it is necessary to know what wood is and how it is actually produced in nature. The amount of wood produced in a growing season depends on species, climate and environment. Therefore, studying the wood properties of ecological and economic species is imperative for utilization and selection for tree improvement programme. According to Zobel and Talbert [2], 70% of the overall specific gravity variation in species is due to genetic control and the remaining 30% is due to the differences among provenances and sites. Specific gravity is correlated with strength or load-bearing capacity of lumber and pulping properties [3]; [4]. Specific gravity, density, moisture content and shrinkage are factors determining the quality of wood and its strength properties. The most important factor affecting shrinkage is wood density, because wood shrinks by an amount that is proportional to the moisture lost from the cell wall [5]. Wood specific gravity, the ratio of oven-dry weight of a given volume of wood to the weight of an equal volume of water [2], is considered to be a good indicator of wood quality, because it is correlated with strength properties of lumber and to wood pulping properties [3]; [4]. Wood density, the weight of wood per unit volume, is another measure of the amount of wood material in a tree and the two are often used interchangeably. Wood density, however, should be reported at certain moisture content, so it is only equal to specific gravity at 0% moisture content. Wood density (specific gravity) is the product of several other traits within a tree including cell diameter, cell wall thickness, and the amount of latewood produced by the tree [2].

Little is known of the variation of *Dipterocarpus indicus* among different populations in Western Ghats of Karnataka, India. Testing of wood for its moisture content is often necessary to assess its conformity to specifications in commercial transaction, in the standardization of strength properties and in the various processes involved in wood utilization in timber industries [6]. With this background the present study was carried out in *D. indicus* to understand the variations among populations for wood properties and to identify the best populations for further tree improvement programmes.

Materials and Methods

Study areas

The study was undertaken in eight sites of Western Ghats of Karnataka from 12° 10' N (Makuta) to 14° 57' N (Devimane) latitude range and from 74° 70' E (Devimane) to 75° 77' E (Sampaje) longitude range (Fig. 1and Table 1). Gundya represents the lower elevation (53 m.a.s.l) while Mudigere has the highest elevation (846 m.a.s.l) among the study sites. The average day's temperature was the maximum in Sringeri site

(34.10°C), while Makuta site recorded the minimum temperature (31.22°C) among the study sites. The average rainfall recorded over a period of ten years (1998 -2008) was highest for Sampaje site (2575.98 mm) and lowest at Kattalekan site (1976.52 mm) (Fig. 2). The study areas fall under tropical climate in Western Ghats region, with April – May being the hottest periods and December – January being the coldest ones, with maximum rainfall during July – August. The soil is lateritic, shallow to medium in depth and reddish brown to dark yellowish brown and in some places black in colour, usually leachable, poor in base saturation, cation exchange capacity and water holding capacity. The chemical properties of soil in all studied sites are shown in Table 2.

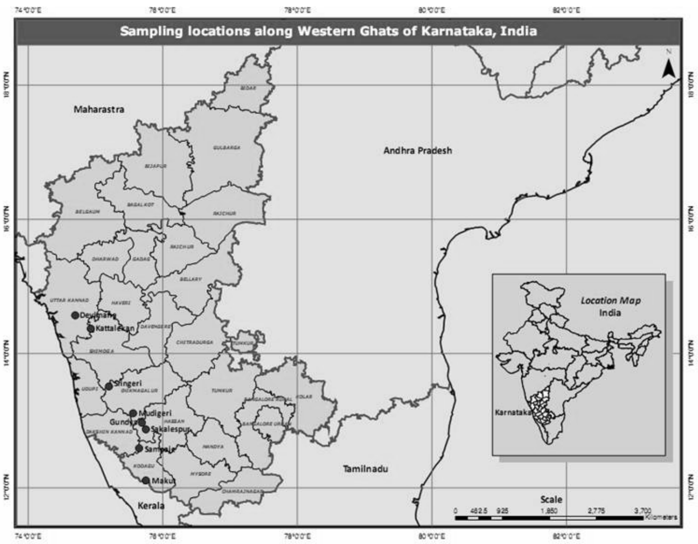


Figure 1: Map of the study areas in the dipterocarp forest of Western Ghats.

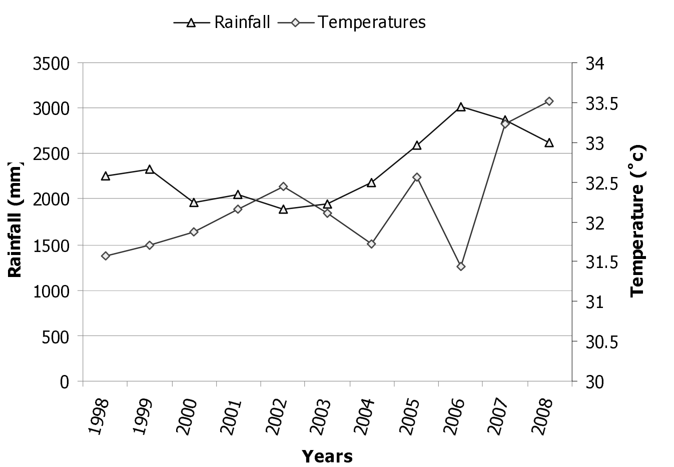


Figure 2: Annual average of rainfall and temperature at the studied areas From 1998-2008. Source: Meteorological Department Bangalore.

Table 1: Geoclimatic details of the study areas.

Region	Latitude (°N)	Longitude (°E)	Altitude (m)	Rainfall* (mm)	Average Humidity %	Temperature* (°C)
Devimane	14.57°	74.70°	480	2119.97	91.63	32.29
Gundya	12.97°	75.69°	153	2523.84	89.63	31.29
Kattalekan	14.37°	74.93°	575	2576.52	91.38	32.48
Makuta	12.10°	75.75°	455	2572.82	89.00	31.22
Mudigere	13.11°	75.56°	846	2145.59	83.75	33.83
Sakleshpura	12.87°	75.75°	793	2039.12	85.50	31.24
Sringeri	13.51°	75.20°	485	2256.12	93.75	34.01
Sampaje	13.59°	75.77°	315	2575.98	91.375	31.32
P-value	-	-	-	-	0.000145	0.005961

*Average rainfall and temperature for 1999-2008
*Source metrological dept. Bangalore.

Table 2: Soil chemical properties of different populations.

		Populations						
Parameters	Makuta	Sakleshpura	Mudigere	Sringeri	Devimane	Kattalekan	Gundya	Sampaje
Sand %	67.90	73.97	96.97	68.13	68.90	69.13	70.97	74.97
silt %	9.97	7.90	7.13	8.97	9.97	6.97	8.13	6.00
Clay %	22.13	18.13	22.90	23.90	21.13	24.90	20.90	19.03
pH	6.96	7.12	6.42	6.56	7.26	6.96	6.62	6.56
EC (DSm-1 at 25° C	1.02	1.27	0.97	0.92	1.37	0.82	1.07	0.87
Organic carbon %	1.19	1.19	0.79	0.90	1.49	1.18	0.82	1.20
Nitrogen (Kg ha -1)	593.80	565.80	495.80	523.80	665.80	583.80	554.80	656.80
phosphors (Kg ha -1)	144.80	122.80	103.80	99.80	152.80	109.80	123.80	153.80
Potassium (Kg ha -1)	391.80	413.80	343.80	341.60	513.80	396.60	383.80	420.80
Sulphur (ppm)	16.24	16.54	14.54	14.84	18.64	15.64	13.57	16.57
Calcium (Cmol. (P+) Kg-1)	6.55	5.85	6.85	6.25	8.25	6.35	7.85	8.80
Magnesium (Cmol. (P+) Kg-1)	2.93	2.93	3.93	2.53	5.33	2.22	3.93	4.30
Zinc (ppm)	1.98	2.18	1.93	2.38	2.48	2.32	2.33	2.53
Copper (ppm)	1.62	2.12	1.72	2.32	2.32	2.10	2.02	2.47
Manganese (ppm)	33.60	32.50	30.20	34.32	36.50	29.96	36.00	32.00
Iron (ppm)	0.96	1.26	0.96	1.26	1.56	0.86	1.21	1.71

Collection of wood samples

Wood samples were collected from 24 trees of *Dipterocarpus indicus* ≥ 30 cm GBH at breast height in eight locations. In each location three trees were selected randomly having a girth class ranging from 120 to 140 cm. selecting a known range of girth mainly to avoid the age effects on wood properties. From each tree, one core sample was extracted at 1.37 m height and 15 cm depth inside the trunk of the trees with the help of Hagloff increment borer. Wood cores were depicted in petri plates containing full of water and preservative (5% formaldehyde). The cores were soaked in water up to 48 hrs and their weights were measured using electronic balance. The cores were dried at 105°C for 72 hrs then wood density (WD), Specific gravity (SG) and moisture content were measured.

Specific gravity

The specific gravity of wood core was determined by the maximum moisture content method [7]

$$Specific\ gravity = 1/(((M_m - M_o)/M_O) + 1/Gso) \quad (1)$$

Where,

M_m = green weight of the sample having maximum moisture

M_o = oven dried constant weight of the sample

Gso= average density of wood substances; constant having value of 1.53.

Density

Density can be calculated following SIMPSON [8] method

$$Density = (D_w / V) * (1 + moisture\ content) \quad (2)$$

Where, D_w is oven-dry wood, V is volume, moisture content 12%

Moisture Content Determination by the Oven Drying Method

The oven drying method is the standard method used to determining wood moisture content as ASTMD4442 [9]. The moisture content (based on dry weight) can be calculated as follows:

$$Moisture\ content\ (MCD) = \frac{Green\ weight - Ovendry\ weight}{Ovendry\ weight} \times 100 \quad (3)$$

Moisture content (based on green weight)

$$\text{Moisture content (MCG)} = \frac{\text{Green weight - ovendry weight}}{\text{Green weight}} \times 100 \quad (4)$$

Maximum moisture content $M_{\max}$ for any specific gravity is calculated.

$$M_{\max}\ (MMC) = \frac{100\ (1.54 - G_b)}{1.54 G_b} \quad (5)$$

Where G_b is basic species gravity (based on ovendry weight and green volume), and 1.54 is specific gravity of wood cell walls.

The moisture content at which wood will sink in water can be calculated by

$$M_{\sin k}\ (SMC) = \frac{100\ (1 - G_b)}{G_b} \quad (6)$$

Equilibrium moisture content.

$$EMC = \frac{1800}{w}\left(\frac{kh}{1-kh} + \frac{k1kh + 2k1k2k^2h^2}{1 + k1kh + K1k2k^2h^2}\right) \quad (7)$$

Where h is relative humidity (%), and M is moisture content (%)
For temperature T Celsius;

$$w = 349 + 1.29T + 0.01357T^2$$

$$K = 0.805 + 0.000736T - 0.00000273T^2$$

$$K_1 = 6.27 - 0.00938T - 0.000303T^2$$

$$K_2 = 1.91 + 0.0407T - 0.000293T^2$$

Shrinkage

The volume shrinkage was determined following Moya and Perez method [10].

$$Shrinkage = \frac{moisture\ weight}{Green\ weight} \quad (7)$$

Where the moisture weight can be calculated as follows [11]

Moistur weight = Md/Vf (8)

Where, Md is the oven-dry mass (dried at 105°C for 72hs) and Vf is the fresh volume.

$$SV = (Gm\,(1 + M/100))/(1 - 0.265aGb) \quad (9)$$

Gm specific gravity based on volume at moisture content M, Gb is basic specific gravity (based on green volume), and a = (30 - M)/30, where M < 30.

Statistic analysis

Analysis of variance (one way ANOVA) and Co-efficient of variance were used following the method of Panse and Sukhatme [12]. The FORTRAN software 5.4 and ME sheet were used to assess the critical differences (CD) among different geographical areas.

$$Co-efficient\ of\ variation\ (\%) = \frac{Standard\ Deviation}{Population\ Means} \times 100 \quad (10)$$

Results

Specific gravity and density

The Results of physical wood properties obtained from core samples of *Dipterocarpus indicus* are presented in Table 3. Wood specific gravity (SG) and density showed statistically significant differences among populations. The maximum SG (0.59) and density (0.66 g m^{-3}) were recorded in the core samples collected from the population of Sakleshpura and Kattalekan whereas the minimum SG (0.45) and density (0.44g m^{-3}) were recorded in core samples of Sampaje. The highest specific gravity and density were recorded in the core samples collected from the populations of Sampaje and Gundya, whereas the lowest SG and Density were recorded in core samples collected from the population of Sakleshpura and Mudigere.

Table 3: variation of wood physical properties of *Dipterocarpus indicus* among different populations

Locations		SG	Density g/m^3	Shrinkage	MCD (%)	MCG (%)	MMC (%)	SMC (%)	SV (%)	EMC (%)
Devimane	M	0.49	0.65	0.52	141.63	58.39	141.63	106.57	0.60	20.15
	R	0.44−0.54	0.63−0.66	0.51-0.53	120.72−164.76	54.69−62.22	120.72−164.76	85.65−129.70	0.53−0.67	18.69−22.12
Kattalekan	M	0.59	0.66	0.50	190.49	65.42	186.94	155.43	0.48	21.16
	R	0.35 −0.42	0.66−0.67	0.51-0.51	173.50−218.09	63.44−68.56	169.95−214.53	138.44−183.02	0.43−0.51	20.33−22.19
Mudigere	M	0.58	0.55	0.58	108.14	51.88	104.58	73.08	0.72	21.61
	R	0.55 − 0.62	0.44−0.60	0.55-0.66	97.15 −117.87	49.28−54.10	93.60−114.31	62.09−82.80	0.68−0.77	19.72−23.61
Sringeri	M	0.46	0.55	0.58	153.60	60.47	150.04	118.532	0.56	22.20
	R	0.44 −0.50	0.47−0.63	0.53-0.63	135.92 −164.91	57.61−62.25	132.36−161.35	100.86−129.84	0.53−0.61	20.82−23.64
Gundya	M	0.58	0.55	0.58	108.18	51.95	104.62	73.11	0.71	17.74
	R	0.56 −0.59	0.488−0.60	0.55-0.62	104.72 −112.37	51.15−52.91	101.16−108.82	69.66−77.31	0.70−0.74	16.41−18.65
Sakleshpura	M	0.59	0.66	0.60	104.56	51.11	103.08	69.49	0.74	19.54
	R	0.59 −0.60	0.49−0.56	0.58-0.62	103.11−105.83	50.77−51.42	117.16−161.20	68.04−70.77	0.7−0.74	18.65−20.28
Makuta	M	0.49	0.65	0.52	143.10	58.44	139.54	108.03	0.60	19.27
	R	0.42−0.57	0.61−0.69	0.49-0.54	112.10−17.69	52.85−63.19	108.54−168.13	77.04−136.62	0.52−0.70	17.34−20.82
Sampaje	M	0.45	0.44	0.65	145.13	58.50	141.567	110.06	0.60	22.45
	R	0.39−0.54	0.40−0.47	0.63-0.69	120.65−192.59	54.68−65.82	117.09−189.03	85.58−157.53	0.47−0.67	21.57−22.92
Grand Mean	M	0.51	0.57	0.57	136.85	57.018	138.38	101.79	0.63	20.52
	R	0.353−0.617	0.40−0.69	0.49-0.69	97.15 −218.09	49.28−68.56	93.59−214.53	62.09−183.02	0.43−0.77	16.41−23.64
CD		0.074	0.09	0.054	34.710	5.404	33.769	35.381	0.097	1.739
SED		0.0345	0.04	0.025	16.1818	2.5192	15.7435	16.4945	0.0453	0.8111
P-value		0.001	0.0014	0.002	0.003	0.001	0.015	0.003	0.001	0.009

*Critical differences (CD), Stander error of difference (SED), P-value @ 0.05.Means (M) and Range (R).

Moisture content

Moisture content variables showed significant variations among core samples collected from *Dipterocarpus indicus* of different populations. The average maximum shrinkage was in wood samples collected from populations of Sampaje (0.65) and Sakleshpura (0.60), whereas the minimum shrinkage was observed in the cores of Kattalekan population (0.50). The shrinkage indicates that the amount of moisture content varies from minimum of 0.49 % to maximum of 0.69 % with average mean of 0.57 %. Interestingly, core samples collected from the population of Kattalekan showed the maximum mean values of MCD (190.49), MCG (65.42), MMC (186.94) and SMC (155.63) whereas the core samples of Sakleshpura showed minimum means with average values of 104.5, 51.11, 103.08 and 69.49, respectively. The coefficient of variance (CV) MCD, MCG, MS, SV and SMC was maximum at core samples of Sakleshpura as shown in Fig. 3,4 and 5. The minimum variation of MCD, MCG, MMC and SV were recorded in core samples of Sakleshpura populations. The volumetric shrinkage was maximum in the core samples collected from the population of Kattalekan where the average values of MCD, MCG, MMC and SMC were minimum. The core samples extracted from the tree population of Sampaje had maximum average of EMC (22.45) whereas the minimum was obtained in the core samples of Gundy (17.74). The Maximum variation of EMC was found in Mudigere, whereas the minimum was found in Sampaje Fig. 5.

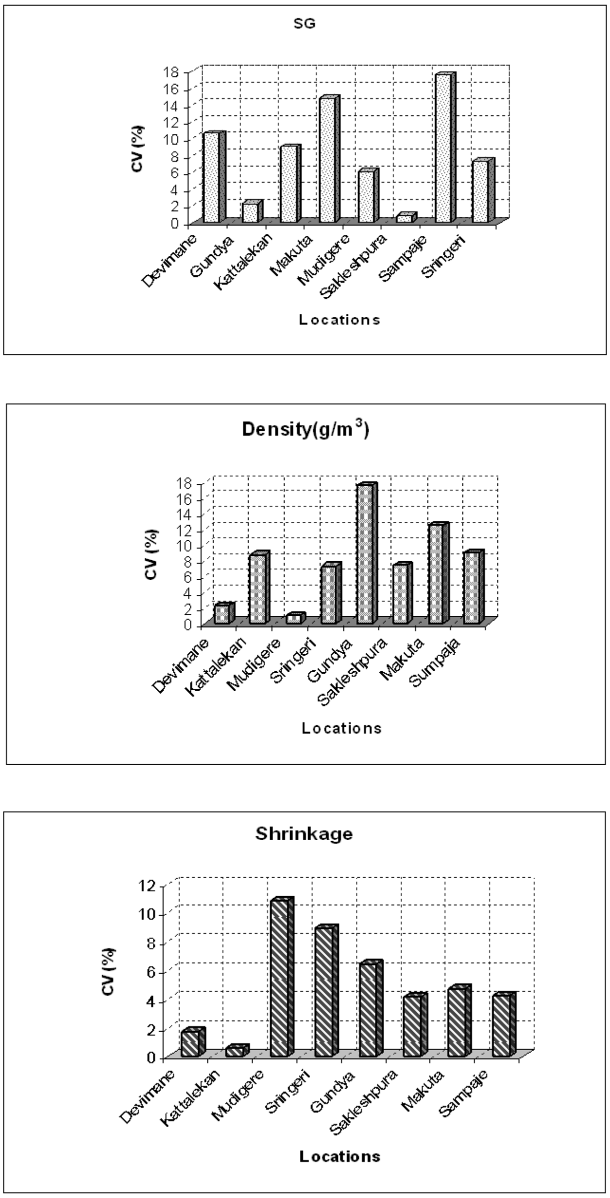


Figure 3: Extent of variation among core samples for SG, Density and Shrinkage.

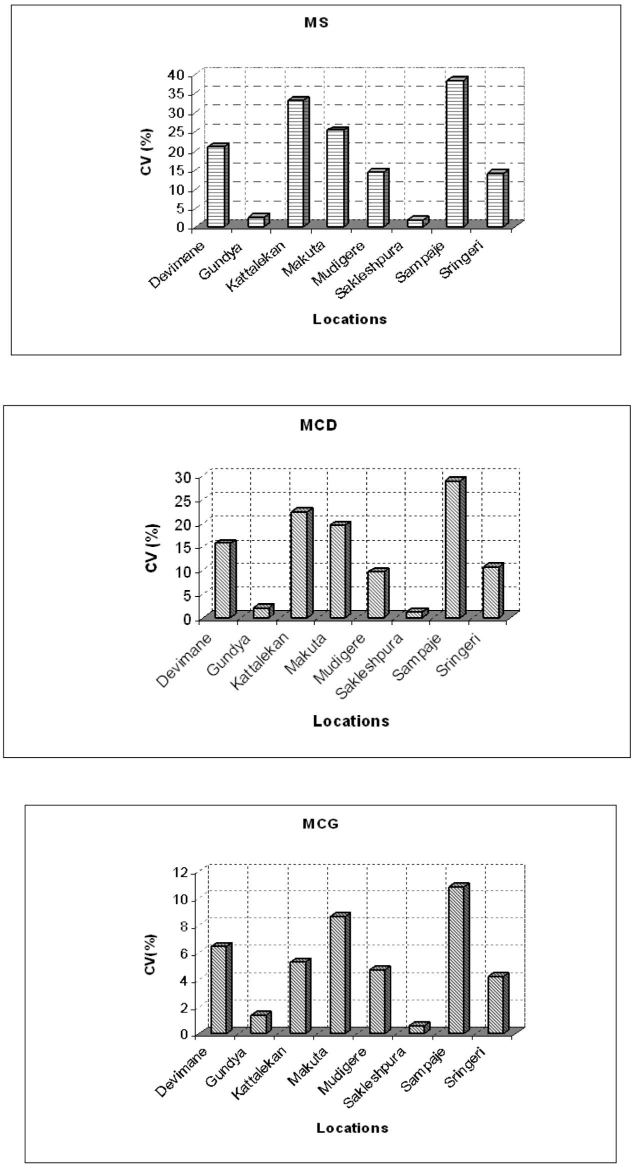
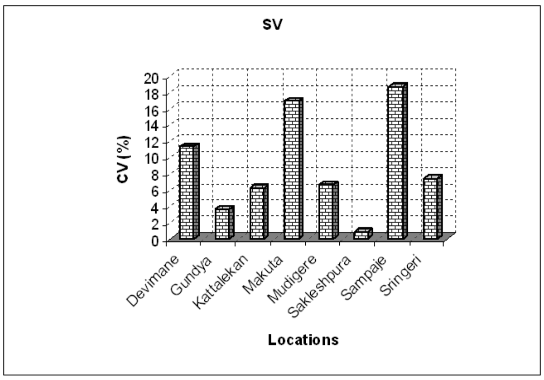
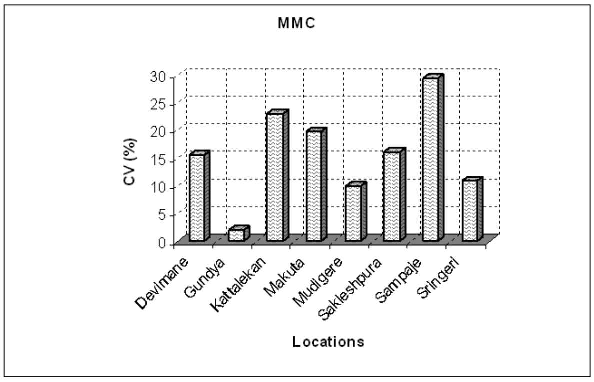


Figure 4: Extent of variation among core samples for MS, MCD and MCG.





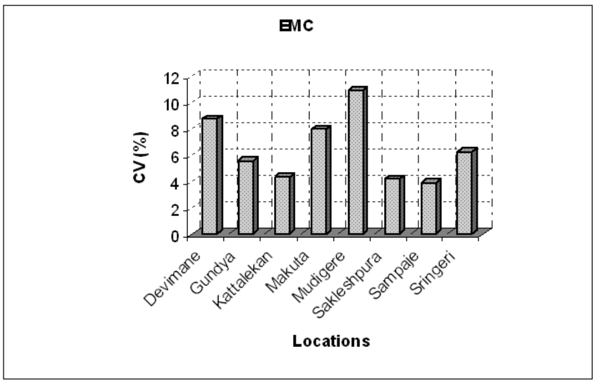


Figure 5: Extent of variation among core samples for SV, MMC and EMC.

Association of wood traits with locality factors

The association of wood specific gravity, density and moisture content with locality factor and among themselves was depicted in Tables 4, 5 and 6. SG was found to be negatively correlated with latitude (r = -0.596), altitude (r = -0.527), rainfall (r =-0.615), temperature (r=-0.466) and clay (r = -0.516). Interestingly, it showed also strong negative association with MCD (r = -0.991), MCG (r = -1.000), MMC (r = -0.888), MS (r = -0.991) and Shrinkage (r = -0.581). In contrary to this SG was found to be associated positively with SV(r = 1.000) and Density (r = 0.464). It was positively correlated with longitude (r = 0.464) and sand (r = 0.495). Density showed significant association with silt (r= 0.519), clay (r = 0.517), pH (r = 0.488) and iron (r = -0.457). Shrinkage associated positively with latitude (r = 0.560), altitude (r = 0.539) and temperature (r = 0.515). It was found to be positively correlated with clay (r = 0.550), MCD (r = 0.608), MCG (r = 0.585) and MS (r = 0.608). It has negatively associated with longitude (r =-0.570), rainfall (r = -0.713) and Electrical Conductivity (EC) (r = -0.435). The MCD was found to be associated negatively with longitude (r = -0.515), rainfall (r= - 0.415), sand (r = -0.413), and EC (r = -0.423). It was found to have high significant and positive correlation with clay (r = 0.509), MCG (r = 0.993), MMC (r = 0.911), MS (r = 1.00) and shrinkage (r = 0.608). MCG associated negatively with longitude (r = -0.537), rainfall (r = -0.408), sand (r= -444), EC (r= -

0.407) and SV (r = -1.000). It showed significant and positive correlation with clay (r = 0.516), MMC (r = 0.892), MS (r = 0.993) and shrinkage (r = 0.585) (Tables 5 and 6). MMC was found to be negative associated with sand % (r = - 0.441) and SV (r = -0.886). It was positively correlated with organic carbon (r = 0.415), MS (r = 0.991) and shrinkage (r= 487). Negative association was found between SMC and longitude (r = -0.515), rainfall (r= - 415), sand (r=-0.413), EC (r = -0.423) and SV (r = -0.989). Positive correlation was found with clay (r = 0.509) and shrinkage (r = 0.608). The VS was correlated negatively with clay (r = -0.516) and shrinkage (r= - 0.578) and positively with longitude (r= 0.542), rainfall (r= 406) and sand (r = 0.415). The EMC was positively correlated with altitude (r = 0.503) and temperature (r = 0.479).

Table 4: Correlation matrix for wood physical properties with geoclimatic factors.

	Latitude	Longitude	Altitude (m)	Rainfall	Temperature
SG	-0.596	0.540*	-0.527	-0.615*	-0.466
MCD %	0.395	-0.515*	0.214	-0.415*	0.148
MCG (%)	0.397	-0.537*	0.226	-0.408*	0.164
MMC (%)	0.366	-0.435*	0.098	-0.319	0.025
SMC (%)	0.395	-0.515*	0.214	-0.415*	0.148
SV (%)	-0.396	0.542*	-0.227	0.406*	-0.166
EMC (%)	0.148	-0.223	0.503*	-0.304	0.479*
DENSITY g/m^3	0.417*	-0.490*	0.225	-0.461*	0.082
Shrinkage (%)	0.560*	-0.570*	0.539*	-0.713*	0.515*

*Significant association @ 0.05 P level, r= ±0.404

Table 5: Correlation matrix for wood physical properties with soil properties.

	SG	MCD (%)	MCG (%)	MMC (%)	SMC (%)	SV (%)	EMC (%)	DENSITY g cm^{-3}	Shrinkage (%)
Sand %	0.449*	-0.413*	-0.444*	-0.441*	-0.413*	0.451*	0.231	-0.290	0.177
silt %	-0.036	-0.026	0.027	-0.034	-0.026	-0.040	-0.356	0.519*	-0.347
Clay %	-0.516*	0.509*	0.516*	0.293	0.509*	-0.516*	0.222	0.517*	0.550*
Ph	-0.158	0.153	0.158	0.345	0.153	-0.159	-0.313	0.488*	-0.145
EC (DSm-1 at 25º C	0.405*	-0.423*	-0.407*	-0.229	-0.423*	0.403	-0.421*	0.138	-0.435*
Organic carbon %	-0.335	0.310	0.332	0.415*	0.310	-0.337	0.001	0.299	0.041
Available nitrogen	-0.304	0.274	0.300	0.272	0.274	-0.306	-0.001	0.078	0.010
Available p2 O5	-0.030	-0.005	0.025	-0.014	-0.005	-0.033	-0.159	-0.008	-0.270
Available K2 O	-0.108	0.085	0.105	0.160	0.085	-0.110	-0.159	0.219	-0.036
Avialable Sulphure	-0.229	0.194	0.224	0.305	0.194	-0.231	0.102	0.208	0.039
Exchangeable Calcium	0.020	-0.047	-0.024	-0.218	-0.047	0.018	0.033	-0.241	0.045
Exchangeable magnesium	0.280	-0.310	-0.285	-0.388	-0.310	0.278	-0.070	-0.134	-0.069
Available zinc	-0.338	0.311	0.335	0.280	0.311	-0.340	0.176	-0.189	0.197
Available copper	-0.262	0.238	0.259	0.281	0.238	-0.264	0.329	-0.339	0.212
Available manganese	0.137	-0.197	-0.146	-0.228	-0.197	0.133	-0.421*	0.106	-0.449*
Availabe iron	0.068	-0.111	-0.074	-0.079	-0.111	0.065	0.161	-0.457*	-0.126

*Significant association @ 0.05 P level, r= ±0.404

Table 6: Correlation matrix among wood physical properties.

	1	2	3	4	5	6	7	8	9
SG	1								
MCD %	-0.991*	1							
MCG (%)	-1.000*	0.993*	1						
MMC (%)	-0.888*	0.911*	0.892*	1					
SMC (%)	-0.991*	1.000*	0.993*	0.911*	1				
SV (%)	1.000*	-0.989*	-1.000*	-0.886*	-0.989*	1			
EMC (%)	-0.284	0.259	0.280	0.169	0.259	-0.285	1		
DENSITY g/m^3	0.464*	0.258	0.264	0.211	0.258	-0.264	-0.247	1	
Shrinkage (%)	-0.581*	0.608*	0.585*	0.487*	0.608*	-0.578*	0.458*	-0.604	1

*Significant association @ 0.05 P level, r= ±0.404

Discussion

Specific gravity and density

Significant differences in specific gravity, density and moisture content were observed among different populations of *Dipterocarpus indicus* (Table 3). Some of these traits have strong trend of influencing by genetic drivers, but our study considered only the locality derivers as a source of variation. Our founding came in line with Zobel and Van Buijtenen [13], who had attributed the variations in wood traits between provenances (populations) in different tree species to genetic, environmental factors and often interaction of both. The significant differences in SG and density among populations could be due to the inconsistency in the environmental factors. The high SG was associated with low fertility, less rainfall, temperature and relative humidity in Sakleshpura and Kattalekan as shown in Tables 1 and 2. A study on wood properties of *Dalbergia latifolia* located at nine different study sites exhibited significant differences for both fiber length and wood specific gravity and the causes were attributed to the site factors [14]. The significant correlation of SG and density with geoclimatic, edaphic factors and physical wood properties emphasized the variations among populations (Tables 4, 5 and 6). So the inclusion of these components should have considerable value in future tree improvement programme. Suzuki [15] and Forest Product Laboratory [9] reported that the moisture content correlated negatively with specific gravity. Ferrari and Scaramuzzi [16] reported that the site has significant influence on wood density of *Populus euramericana* and the variance showed that site accounted for 71% of wood density variation. Wood density or specific gravity varies among trees and among geographic locations. Among-tree variation accounts for a large portion of the variation of specific gravity in loblolly pine and this variation has been attributed to genetic differences among trees within a stand [17]. Zobel and Van Buijtenen [13] reported that the northern and inland areas of loblolly pine tend to be lower in specific gravity than coastal and southern areas. Wood density is considered as one of the most important wood properties which has a major impact on the properties and value of both fibrous and solid wood products. Based on the value of specific gravity, Limaye [18] classified the wood for commercial fields into very light below 0.28, light 0.28-0.42, moderately heavy 0.42-0.56 and heavy 0.56- 0.70. Our study found that the wood of *Dipterocarpus indicus* classified into two qualities: moderate heavy (0.45) in the core samples collected from the population of Sampaje and heavy (0.59) in the core samples collected from the populations of Sakleshpura and Kattalekan. These may be due to the amount of solid materials occupying more space in heavy wood, and less space remained for air and water as shown in the core samples collected from Sakleshpura. Water content was less variable in heavy wood than in light wood. In a fresh condition, wood of some light-wood species included a lot of water and was heavy while others included less water and were light. Suzuki [15] explained the negative correlation between SG and MC to the amount of solid materials, air and water in cell wood.

Moisture content

Timber is very sensitive to moisture and it is vital to understand all aspects of the interaction between timber and moisture in order to be used wisely. Weight, shrinkage, strength, and other wood properties depend upon the moisture content. The significant variation in moisture content of different wood core collected from different populations could be due to the site factors and anatomical characteristics of wood. Brough et al. [19] reported that the water contents of wood are probably affected by the habitat. Suzuki [15] stated that the water content may change with season and climate. A lot of variations were found among populations for density, specific gravity and moisture content. Therefore one could expect a narrow variation of these traits among the different populations but surprisingly, the population of different study sites showed significant difference with broad variation. Interestingly, such significant differences were found to be influenced by the site factors. The variations in moisture content could be attributed to the non hereditary factors such as, variation in climate, site quality stand environment (competition among individual trees), genetic factors and the interaction between both also had a vital role in variation among provenance (populations) as shown in Tables 1 and 2. Wang et al. [20] reported that the variations in density and moisture content of wood and bark among twenty *Eucalyptus grandis* progenies were significant. Also the variation in wood properties was largely due to the genetic differences. Variation has been observed from the heartwood to the bark, along the length of the bole (the trunk below the first large branch) among different components in a given tree and between individuals of same species. This variation reflects the interaction of the plant with environmental factors, such as climatic and edaphic conditions, natural impacts and competition for light [21]; [22]; [23]; [24]; [25]; [26]. Furthermore, the variation in adaptive traits at provenance and family level may be affected by different factors [27]. For provenances a common influence of the climatic conditions during reproduction on the offspring could be important for the relationships observed. For families from the same geographic region this influence is most likely reduced. Such influences could explain the differences in trait relationships at the provenance and family level.

Shrinkage of wood due to loss of moisture is a common phenomenon. Shrinkage of wood during drying is caused by changes in the moisture content below the fiber saturation point and is more or less directly proportionate to the change in the water content of cell wall [28]. The high shrinkage was observed in the core samples collected from Kattalekan, this could be attributed to the high average in rainfall, humidity and temperature (Table 1). The final longitudinal shrinkage of birch of wood is dependent on temperature rather than heat rate [29]. Shrinkage was found to be a function of wood species, heat flux, and temperature [30]. Kokutse et al. [31] found that wood density and moisture content depend on site location. Yamashita et al. [32] reported that the tangential shrinkage is largely controlled by changes in latewood, because latewood is strong enough to force early wood to comply with it. The factors that contribute to transverse shrinkage might vary depending on the anatomical structure and its variation within each species.

The correlation matrix among wood properties showed that there was no relationship between wood density and wood moisture content. Our finding came in accordance of Wang et al. [20] who had reported that no relationship was found between wood density and wood moisture content. A low wood density may be obtained on sites with favourable soil properties for stand growth (particularly tree diameter) with consequent low quality for structural uses [33]. Other studies on teak in Central America report the relationship of wood production with physical characteristics of soil. [34]; [35] indicate that a reduction of 3% occurs in the average stand growth when the pH levels fall below 6, while an optimum growth rate takes place when the calcium level is superior to 68 % on teak plantations in Costa Rica and Panama. The strong negative correlation obtained in this study between SG and moisture content was also reported by McNatt, [36] Strength and stiffness decrease significantly at higher relative humidity (RH). as much as 50 percent at 90 percent RH, when compared to properties at standard conditions of 65 percent RH. This can be attributed to the accelerated rate of change in EMC

Conclusions

The most important conclusion of the current study is that the wood physical properties of *Dipterocarpus indicus* showed significant variation among different populations. Specific gravity, density and moisture content were affected by environmental factors. The correlation matrix showed that the SG was correlated negatively with moisture content and geoclimatic factors. Therefore, the wood was classified based on the SG in to moderate heavy and very heavy wood. The variation in wood quality of *Dipterocarpus indicus* resulted from the variation in locality factors among different populations. These variations in physical wood properties could be efficient and would be utilized for population selection for further tree improvement programmes.

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