International Journal of Ecology and Environmental Sciences 51: 645-659, 2025
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2025.0838

Wood Specific Gravity of Trees Outside Forest in India: A Review

SYLVAIN MEINRAD DONKENG VOUMO[1] AND NARENDRA KUMAR MAURYA[2*]
[1]Department of Environmental Sciences, [2]Department of Civil Engineering (Environmental Engineering), Gokul Global University, Sidhpur (Patan), India
E-mail: sylvainmeinrad@yahoo.com, narendramaurya.cvl.hcet@gokuluniversity.ac.in
[*]**Corresponding author**

ABSTRACT
Wood Specific Gravity (WSG) is one of the most important and significant parameter for accurately estimating the aboveground biomass and carbon stocks of trees. In India, estimation of Biomass and carbon stocks for Trees Outside Forest (TOF) often rely on generalized or international WSG databases, leading to significant uncertainties in national carbon inventories. This study addresses this gap by developing the first comprehensive, national-level WSG inventory specifically for TOF in India. Through a systematic review of 103 peer-reviewed articles and 3 grey literature reports, we compiled an extensive database of WSG values. The resulting inventory covers 216 tree individuals belonging to 120 species, 86 genera, and 37 families, categorized by TOF system (agroforestry, urban plantations, rural plantation and mixed systems), growth stage (juvenile and mature), and geographical location. Our results reveal substantial WSG variability, with values ranging from 0.20 (*Ailanthus excelsa*) to 0.96 (*Hymenodictyon excelsum*). Variations were observed between TOF categories and, critically, between mature and juvenile growth stages, with mature trees generally exhibiting higher wood density. The compiled data demonstrates that using context-specific WSG values from this inventory can substantially reduce errors compared to using generic values. This dataset provides a critical resource for improving the precision of biomass and carbon accounting for India's TOF, thereby supporting national climate change mitigation strategies, REDD+ (Reducing Emissions from Deforestation and Forest Degradation, with conservation, sustainable management of forests and enhancement of forest carbon stocks) reporting, and sustainable land management policies.

Key words: Biomass Estimation, Carbon Stock, Climate change, India, Trees Outside Forest, Wood Specific Gravity

INTRODUCTION

Trees Outsides Forest (TOF) in India, as in many other countries, are trees in landscapes located outside the national recorded forest area (RFA) recognised by the Ministry of Forest, environment and Climate Change (Anonymous 2023). They include agroforestry systems, orchards, and urban and peri-urbans trees (Skole et al. 2021, Thapa et al. 2021, Tamang et al. 2021, Tassew 2017, Tewari et al. 2014). Incorporating TOF into India's National Biomass and Carbon Inventory within MRV systems and the REDD+ mechanism (Reducing Emissions from Deforestation and Forest Degradation, with conservation, sustainable management of forests and enhancement of forest carbon stocks) advances a more comprehensive and fairer climate framework that recognises the ecological value of all trees (Anonymous 2023, Shrestha et al. 2019). Biomass and carbon of TOF are commonly estimated non destructively by multiplying allometric/volumetric equations with Wood Specific Gravity (WSG) (Sylvain and Narendra 2024). WSG, the ratio of oven dry weight to green volume is fundamental because it tracks organic matter and carbon content (Mihriemate et al. 2020, Baqir et al. 2017). Although many TOF biomass studies exist (Pati et al. 2024, Jeevan et al. 2025, Tamang et al. 2021, Nandal et al. 2019, Flora et al. 2018, Haghparast et al. 2013), Indian work often applies generalised or foreign WSG values (Zanne et al. 2009, Chave et al. 2006, Reyes et al. 1992), overlooking climate, soil, maturity, and vegetation effects (Sylvain and Narendra 2024, Babita et al. 2024, Ramesh and Rao 2016). Species specific WSG data are frequently absent in herbal gardens, roadside plantations, and urban landscapes, prompting use of congeners or omission (Veeranjaneyullu et al. 2023, Pati et al. 2022, Mihriemate et al. 2020). Such substitutions can overestimate aboveground biomass by 150 million megagrams at state scale and 660 million megagrams nationally; habitat specific WSG is urged

for mature and juvenile trees. Building on WSG compilations that reduced forest carbon errors (Pati et al. (2025), Pati et al. (2022)), this study aggregates scattered WSG values for trees outside forests to lessen biomass and carbon bias in non forest environments.

METHODS

Study design and scope

This study aimed to establish a comprehensive inventory of wood specific gravity (WSG) values for trees outside forests (TOF) across diverse regions of India. The scope included species from urban plantations, rural plantations, agroforestry systems and scattered Trees Outside Forest (Mixed TOF). It emphasized both mature and juvenile stages to reduce error in biomass estimations, particularly in the context of climate-specific and Trees Outside Forest-Categories-specific variations.

Literature collection and screening process

A systematic literature review (Fig. 1) was conducted following protocols adapted from Pati et al. (2025, 2022) and Gargaran et al. (2024), integrating both peer-reviewed articles and grey literature. The search was performed across multiple databases including Scopus, Google Scholar, ResearchGate, and

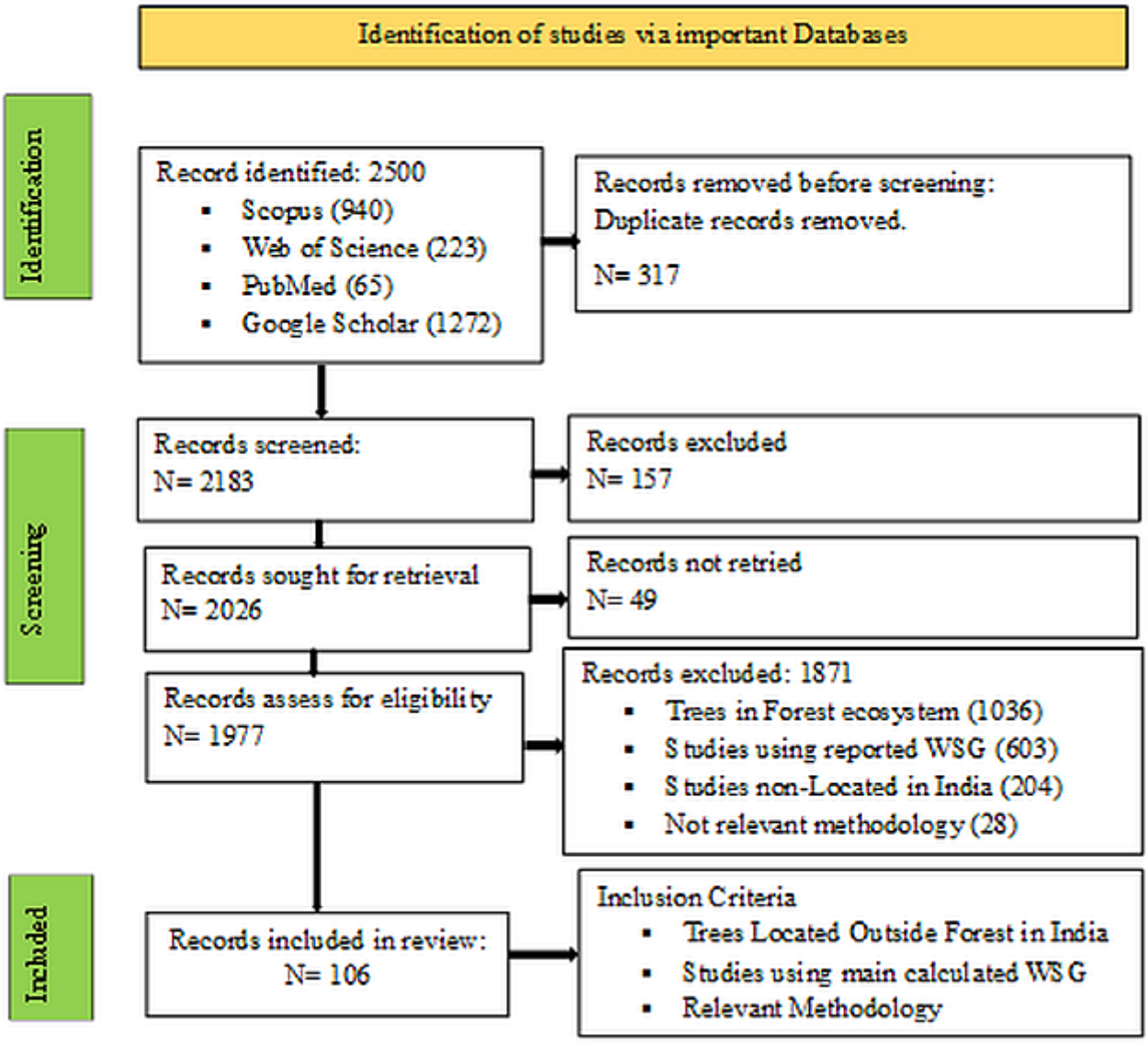

Figure 1. PRISMA flow diagram for the identification of studies for inclusion in systematic review of WSG inventory of Trees Outside Forest in India

university repositories using combinations of keywords such as *"wood specific gravity", "biomass estimation", "TOF India", "carbon stock", "non-forest trees"*, and *"functional traits"*. Boolean operators were used to narrow the scope, and inclusion was limited to studies conducted within India and reporting direct or calculated WSG values. Out of 2500 initially identified records, a total of 2183 articles were screened based on titles and abstracts, and 1977 full texts were assessed for eligibility. Studies using only reported or default WSG values without field validation were excluded, yielding a final dataset of 103 peer-reviewed articles and 3 grey literature report, including research trials and regional biomass assessments.

Classification and metadata compilation

Data were extracted and compiled into Microsoft Excel. For each species, the following metadata were recorded: Botanical name (Genus, species, family); Stage of development (juvenile or mature); WSG values; Area location (district, state, agro-climatic zone); Category of TOF (rural and urban plantations, agroforestry trees, Mixed TOF); Method of WSG determination, Reference and publication year.

Determination of WSG of TOF in India

Sample collection and processing methods

In India, two main sampling methods are predominantly used to collect wood samples for specific gravity estimation: the disk method and the increment core method. Early studies often adopted the disk method, which involves cutting cross-sections (disks) from the bole or branches at different heights. While this approach allows for comprehensive intra-tree analysis (radial or axial variations), it is destructive as it requires felling of trees or large branches. More recent investigations employ the increment core method, which uses increment borers to extract cylindrical wood cores from standing trees. This method is non-destructive and suitable for long-term monitoring of sample trees. It has gained popularity in India for assessing wood specific gravity in agroforestry trials, plantation forestry, and clonal selection programs. In the study by Pande and Singh (2005), increment cores were taken from *Dalbergia sissoo* clonal ramets at Dehradun and Haldwani, which were then analyzed for WSG. SriLakshmi and Rao (2004) extracted increment cores from *Eucalyptus tereticornis* clones in Karnataka. Meena et al. (2016) also followed core-based sampling for *Tectona grandis* in Maharashtra. Sharma et al. (2023) used cores and cross-sections from *Pinus roxburghii* to assess oleoresin production and wood density. Processing methods generally involve drying samples in an oven at 103±2°C until constant weight is achieved, followed by measurement of either green volume or dry volume, depending on the method of WSG estimation.

Methods adopted for determining wood specific gravity in India

Two principal techniques are used in Indian research for calculating Wood Specific Gravity (WSG):

a) Forest Products Laboratory Method (Anonymous 1952)

$$WSG = D / V$$

where D is the oven-dry weight (g) and V is the green volume (cm^3), measured either by water displacement or dimensional method ($V = \Pi/4 \times D^2 \times L$).

b) Maximum Moisture Content Method (Smith 1954)

This method uses the weight of saturated and oven-dried samples, avoiding the need to measure volume.

$$Gf = 1 / ((Mm - Mo)/Mo + 1/Gso)$$

where Mm = saturated weight, Mo = oven-dry weight, and Gso (Basic specific gravity) = 1.53. This method is convenient but requires proper saturation to avoid errors.

RESULTS

WSG values in Indian TOF communities

A survey of literature for wood specific gravity (WSG) in Indian Trees Outside Forests (TOF) communities revealed that WSG values of 216 tree individuals belonging to 120 species, 86 genera, and 37 families are available for Indian TOF communities. Among these, WSG values for 52 woody species were reported for mature growth stages, 17 woody species for juvenile stages, and 51 woody species for which the growth stage was unspecified (Fig. 2).

The TOF categories with the highest number of species were found in Agroforestry Trees and Urban

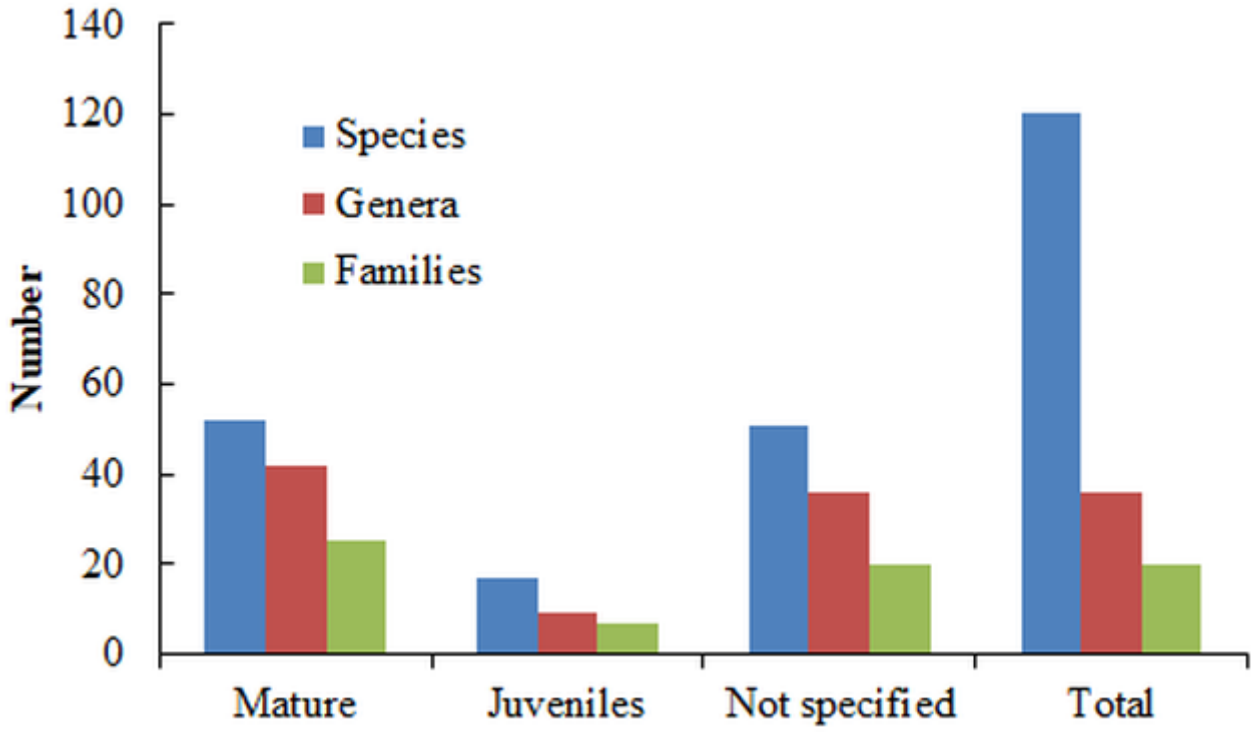

Figure 2. Number of species, genus and families for which WSG values available in Indian TOF communities

Trees Plantations, both Mixed TOF and Rural Trees Plantations had fewer species (Fig. 3). For mature individuals across all TOF categories, the highest WSG was observed for *Hymenodictyon excelsum* (0.96) in Urban Trees Plantations, and the lowest for *Bombax ceiba* (0.26) in Agroforestry Trees. For juvenile individuals, the highest WSG was reported for *Casuarina equisetifolia* (0.82) in Urban Trees Plantations, and the lowest for *Ailanthus excelsa* (0.200-0.292) in the same category (Table 1).

WSG range distribution analysis showed that for mature individuals, the majority of species had WSG values between 0.61-0.80, while the fewest species fell in the 0.20-0.40 range. For juvenile individuals, most species had WSG values between 0.41-0.60, with very few in the 0.81-1.00 range (Fig. 4). Analysis of WSG range distribution among TOF categories indicated that while Agroforestry Trees exhibited the widest range of WSG values, the Rural Trees Plantations showed the narrowest range (Fig. 5). The highest mean WSG was observed in Mixed TOF and the lowest was in Urban Trees Plantations (Table 1). Overall, the study highlights that WSG values vary significantly depending on the TOF category and growth stage, suggesting that environmental and management factors influence wood density in non-forest tree systems.

WSG values from different categories of TOF

Agroforestry Trees

Agroforestry Trees represent a significant component of TOF in India, integrating trees with agricultural systems. WSG values for mature trees in that category ranged from 0.20 (*Ailanthus triphysa*) to 0.889 (*Anogeissus pendula*). For juvenile trees, the range was 0.418-0.500 (*Melia dubia*). The highest WSG for mature trees was observed in *A. pendula*, while the lowest was in *A. triphysa*.

Urban Trees Plantations

Urban Trees Plantations are critical for urban greening and ecosystem services. WSG values for mature trees ranged from 0.26 (*Bombax ceiba*) to 0.96 (*H. excelsum*), while juvenile trees ranged from 0.20-0.292 (*A. excelsa*) to 0.82 (*C. equisetifolia*). The highest WSG was recorded for *H. excelsum*, and the lowest for *B. ceiba*.

Mixed TOF

Mixed TOF includes trees scattered outside traditional forest areas. WSG values for mature trees

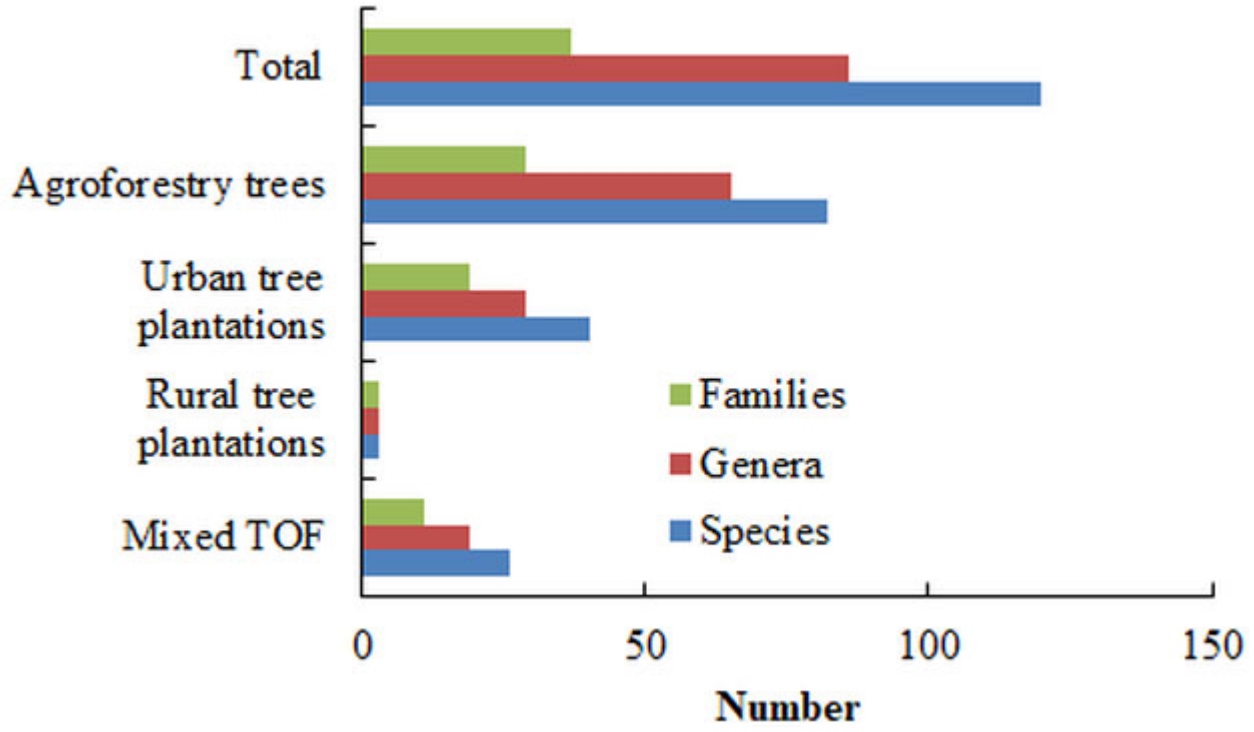

Figure 3. Number of woody tree species studied for their wood specific gravity in each TOF categories

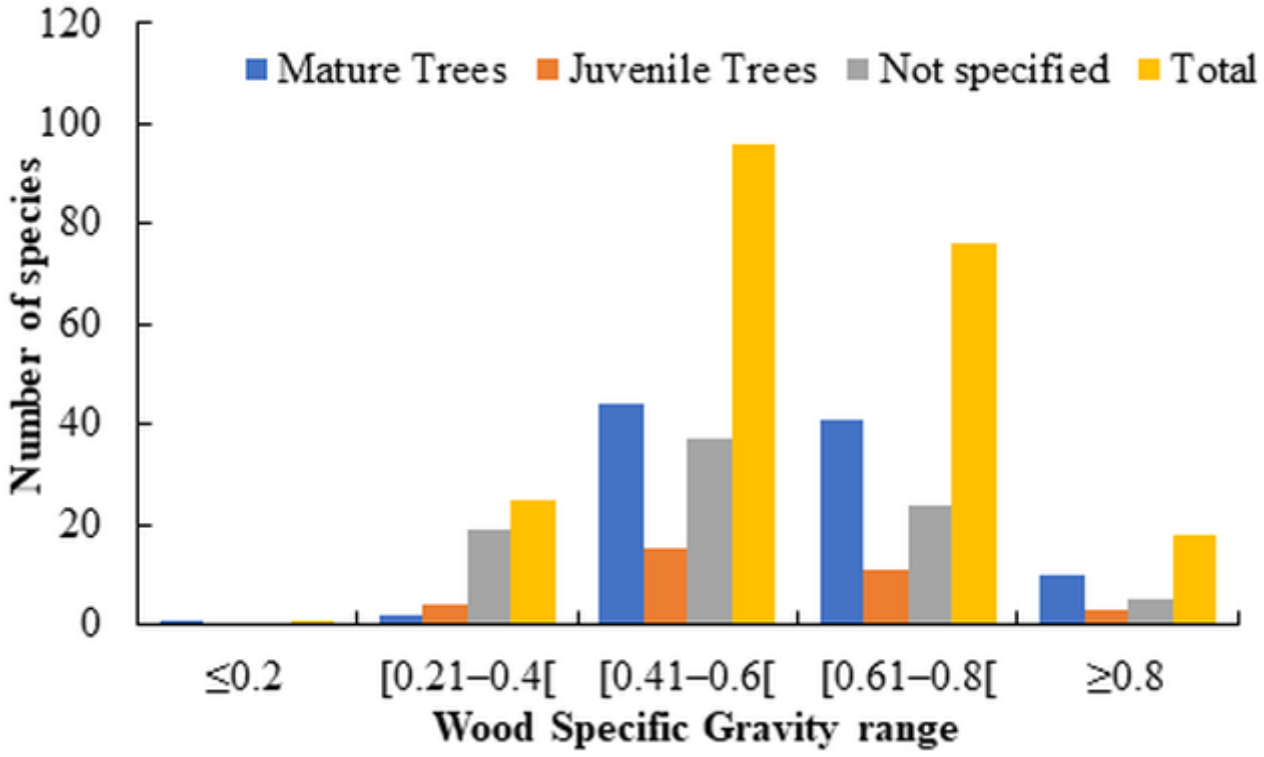

Figure 4. WSG range among different growth stages of studied species in TOF communities

Table 1. WSG values of different species of TOF for both mature and juvenile growth stages in India

Tree species	WSG value	Growth stage	Category of TOF	Location	Sources
Acacia nilotica	0.721	Mature	AT	Jhalawar district, Rajasthan	Meghwal et al. 2020
Acacia auriculiformis	0.703	Mature	AT	India (NS)	Shukla et al. 2007
Acacia catechu	0.67	Mature	AT	Punjab	Chauhan et al. 2009
Acacia nilotica	0.64	Mature	AT	Punjab	Chauhan et al. 2009
Acacia mangium	0.5	Mature	AT	Thrissur district, Kerala	Shanavas and Kumar 2006
Acacia auriculiformis	0.637	Mature	AT	Thrissur district, Kerala	Shanavas and Kumar 2006
Acacia auriculiformis	0.774 ± 0.095	Mature	Mixed TOF	Tamil Nadu	Sundarapandian et al. 2014
Acacia mangium	0.570 ± 0.025	Mature	Mixed TOF	Thrissur district, Kerala	Ramanan et al. 2018
Acacia catechu	0.815	NS	Mixed TOF	Jalaun district, Uttar Pradesh	Chavan 2016
Acacia leucophloea	0.744	NS	Mixed TOF	Jalaun district, Uttar Pradesh	Chavan 2016
Acacia nilotica	0.63	NS	Mixed TOF	Jalaun district, Uttar Pradesh	Chavan 2016
Acacia senegal	0.729	NS	Mixed TOF	Jalaun district, Uttar Pradesh	Chavan 2016
Acacia auriculiformis	0.5	Juvenile	UTP	Uttar Kannada, Karnataka	Shukla et al. 2007
Acacia auriculiformis	0.57	Mature	UTP	Uttar Kannada, Karnataka	Shukla et al. 2007
Acacia auriculiformis	0.62	Mature	UTP	Uttar Kannada, Karnataka	Shukla et al. 2007
Acacia auriculiformis	0.8	Mature	UTP	Neyveli, Tamil Nadu	Mayavel et al. 2021
Acacia nilotica	0.66	Mature	UTP	Uttarakhand	Sharma et al. 2016
Acrocarpus fraxinifolius	0.51	Mature	AT	Punjab	Chauhan et al. 2009
Acrocarpus fraxinifolius	0.51	NS	UTP	Tamil Nadu	Vennila 2021
Aegle marmelos	0.76–0.91	Mature	MTOF	Assam district, Uttar Pradesh	Negi 1963
Ailanthus triphysa	0.36	NS	AT	Kerala	Shanavas and Kumar 2003
Ailanthus excelsa	0.200-0.292	Juvenile	UTP	Navsari district, Gujarat	Patel et al. 2022
Albizia lebbeck	0.598	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Albizia procera	0.56	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Albizia lebbeck	0.55	Mature	UTP	Tamil Nadu; Andhra Pradesh	Marimuthu 2015
Albizia lebbeck	0.58	Mature	UTP	Uttarakhand	Sharma et al. 2016
Albizia lebbeck	0.53	NS	UTP	Tamil Nadu	Vennila 2021
Alstonia scholaris	0.33	NS	AT	Kerala	Shanavas and Kumar 2003
Anacardium occidentale	0.47	NS	AT	Kerala	Shanavas and Kumar 2003
Annona squamosa	0.46	NS	AT	Kerala	Shanavas and Kumar 2003
Anogeissus latifolia	0.832	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Anogeissus pendula	0.889	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Anogeissus pendula	0.701	NS	MTOF	Jalaun district, Uttar Pradesh	Chavan 2016
Anthocephalus cadamba	0.44	Mature	AT	Punjab	Chauhan et al. 2009
Areca catechu	0.52	NS	AT	Kerala	Shanavas and Kumar 2003
Artocarpus heterophyllus	0.46	NS	AT	Kerala	Shanavas and Kumar 2003
Artocarpus hirsutus	0.49	NS	AT	Kerala	Shanavas and Kumar 2003
Artocarpus heterophyllus	0.54	Mature	MTOF	Thrissur district, Kerala	Sunny et al. 2020
Artocarpus hirsutus	0.53	Mature	UTP	Uttara Kannada, Karnataka	Sangeetha et al. 2018
Averrhoa carambola	0.61–0.75	Mature	AT	Sunderbans, Bengal	Ghosh and Purkayastha 1963
Azadirachta indica	0.711	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Azadirachta indica	0.778 ± 0.015	Mature	MTOF	Tamil Nadu	Sundarapandian et al. 2014
Azadirachta indica	0.646	NS	MTOF	Jalaun district, Uttar Pradesh	Chavan 2016
Bambusa balcooa	0.68	Juvenile	UTP	Mettupalayam, Tamil Nadu	Selvan et al. 2017
Bombax ceiba	0.26	Mature	AT	Punjab	Chauhan et al. 2009
Bombax ceiba	0.415	Mature	UTP	Solan, Himachal Pradesh	Gupta et al. 2016
Boswellia serrata	0.446	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Butea monosperma	0.512	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Careya arborea	0.52	NS	AT	Kerala	Shanavas and Kumar 2003
Caryota urens	0.3	NS	AT	Kerala	Shanavas and Kumar 2003
Cassia fistula	0.73	NS	AT	Kerala	Shanavas and Kumar 2003
Casuarina equisetifolia	0.70 - 0.83	Juvenile	UTP	Karur district, Tamil Nadu	Vishnu et al. 2018
Casuarina equisetifolia	0.82	Mature	UTP	Sirsi, Karnataka	Sangeetha et al. 2018
Casuarina MTP	0.54	NS	UTP	Tamil Nadu	Vennila 2021
Ceiba pentandra	0.24	NS	AT	Kerala	Shanavas and Kumar 2003
Celtis australis	0.573	Mature	UTP	Solan, Himachal Pradesh	Gupta et al. 2016
Citrus aurantium	0.71	Mature	AT	West Bengal	Negi 1963
Citrus medica	0.74	Mature	AT	Dehra Dun, Uttar Pradesh	Negi 1963

Tree species	WSG value	Growth stage	Category of TOF	Location	Sources
Dalbergia sissoo	0.743	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Dalbergia sissoo	0.68	Mature	MTOF	Himachal Pradesh	Sunny et al. 2020
Dalbergia sissoo	0.517–0.644	Mature	MTOF	Himachal Pradesh	Sunny et al. 2019
Dalbergia sissoo	0.646	NS	MTOF	Jalaun district, Uttar Pradesh	Chavan 2016
Dalbergia sissoo	0.69	Mature	UTP	Uttarakhand	Sharma et al. 2016
Dalbergia sissoo	0.429–0.596	Mature	UTP	Dehradun and Haldwani, Uttaranchal	Pande et al. 2005
Dalbergia paniculata	0.35	NS	UTP	Tamil Nadu	Vennila 2021
Dalbergia sissoo	0.58	NS	UTP	Tamil Nadu	Vennila 2021
Delonix regia	0.42	NS	AT	Kerala	Shanavas and Kumar 2003
Diospyros montana	0.44-0.81	Mature	MTOF	Solan, Himachal Pradesh	Saini et al. 2024
Erythrina indica	0.22	NS	AT	Kerala	Shanavas and Kumar 2003
Erythrina indica	0.438	NS	UTP	Tamil Nadu	Vennila 2021
Eucalyptus tereticornis	0.53	Mature	AT	Punjab	Chauhan et al. 2009
Eucalyptus sp	0.89-0.95	Juvenile	MTOF	Bissamcuttack, Titlagarh, Odisha	Sahoo et al. 2020
Eucalyptus tereticornis	0.642	NS	MTOF	Jalaun district, Uttar Pradesh	Chavan 2016
Eucalyptus sp	0.64±0.05	Juvenile	UTP	Karnataka, Andhra Pradesh, Tamil Nadu and Kerala	Dasgupta et al. 2021
Eucalyptus grandis	0.63±0.04	Juvenile	UTP	Karnataka, Andhra Pradesh, Tamil Nadu and Kerala	Dasgupta et al. 2021
Eucalyptus grandis	0.425-0.501	Juvenile	UTP	Idukki District, Kerala	Pillai et al. 2013
Eucalyptus sp	0.45-0.62	Juvenile	UTP	Tamil Nadu	Parveen et al. 2021
Eucalyptus sp	0.5838-0.6129	Juvenile	UTP	Andhra Pradesh, Tamil Nadu, and Telangana	Kamalakannan et al. 2023
Eucalyptus sp	0.89 - 0.95	Juvenile	UTP	Bissamcuttack, Titlagarh, Odisha	Sahoo 2018
Eucalyptus sp	0.45 - 0.70	Juvenile	UTP	Navsari, Gujarat	Huse et al. 2024
Eucalyptus sp	0.587 -0.625	Juvenile	UTP	Andhra Pradesh, Tamil Nadu, and Telangana	Kamalakannan et al. 2023
Eucalyptus tereticornis	0.66±0.03	Juvenile	UTP	Karnataka, Andhra Pradesh, Tamil Nadu and Kerala	Dasgupta et al. 2021
Eucalyptus tereticornis	0.570-0.624	Juvenile	UTP	Kollam District, Kerala	Pillai et al. 2013
Eucalyptus tereticornis	0.815	Juvenile	UTP	Kolar district, Karnataka	Sharma et al. 2005
Eucalyptus camaldulensis	0.6003-0.6108	Juvenile	UTP	Andhra Pradesh, Tamil Nadu, and Telangana	Kamalakannan et al. 2023
Eucalyptus grandis	0.63±0.04	Juvenile	UTP	Karnataka, Andhra Pradesh, Tamil Nadu and Kerala	Dasgupta et al. 2021
Eucalyptus sp	0.441 ± 0.552	Juvenile	UTP	Tumkur District, Karnataka	Sharma et al. 2015
Eucalyptus tereticornis	0.577-0.618	Juvenile	UTP	Mandya, Kolar, Karnataka	SriLakshmi et al. 2004
Eucalyptus tereticornis	0.63	Mature	UTP	Uttara Kannada, Karnataka	Sangeetha 2018
Eucalyptus tereticornis	0.72	Mature	UTP	Uttarakhand	Sharma et al. 2016
Eucalyptus tereticornis	0.822	Mature	UTP	Kolar district, Karnataka	Sharma et al. 2005
Eucalyptus sp	0.525	NS	UTP	Tamil Nadu	Vennila 2021
Ficus religiosa	0.39	NS	AT	Kerala	Shanavas and Kumar 2003
Ficus benghalensis	0.41	NS	AT	Kerala	Shanavas and Kumar 2003
Garuga pinnata	0.4	NS	AT	Kerala	Shanavas and Kumar 2003
Gliricidia sepium	0.58	NS	AT	Kerala	Shanavas and Kumar 2003
Gmelina arborea	0.45	NS	AT	Punjab	Chauhan et al. 2009
Gmelina arborea	0.36	NS	AT	Kerala	Shanavas and Kumar 2003
Grevillea robusta	0.478	NS	AT	Kerala (Thrissur)	Shanavas and Kumar 2003
Grevillea robusta	0.53 ± 0.01	NS	MTOF	Uttarakhand	Bhandari et al. 2023
Grewia tillaefolia	0.7	NS	RTP	Uttara Kannada, Karnataka	Sangeetha et al. 2018
Grewia tillifolia	0.485	NS	UTP	Tamil Nadu	Vennila 2021
Gyrocarpus jacquinii	0.326	NS	UTP	Tamil Nadu	Vennila 2021
Hevea brasiliensis	0.648 ± 0.031	Mature	UTP	Cochin district, Kerala	Hossain et al. 2018
Holigarna arnottiana	0.31	NS	AT	Kerala	Shanavas and Kumar 2003
Holoptelea integrifolia	0.536	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Hopea parviflora	0.76	NS	AT	Kerala	Shanavas and Kumar 2003
Hydnocarpus pentandra	0.53	NS	AT	Kerala	Shanavas and Kumar 2003
Hymenodictyon excelsum	0.96	Mature	UTP	Kerala	Hegde et al. 2014
Lagerstroemia microcarpa	0.51	NS	AT	Kerala	Shanavas and Kumar 2003
Lannea coromandelica	0.47	Mature	MTOF	Jhalawar District, Rajasthan	Meghwal et al. 2020
Leucaena leucocephala	0.647	NS	MTOF	Jalaun district Uttar Pradesh	Chavan 2016

Tree species	WSG value	Growth stage	Category of TOF	Location	Sources
Macaranga peltata	0.28	NS	AT	Kerala	Shanavas and Kumar 2003
Mallotus philippensis	0.53	NS	AT	Kerala	Shanavas and Kumar 2003
Mangifera indica	0.6	Mature	AT	Lucknow, Uttar Pradesh	Kushwaha 2022
Mangifera indica	0.703 ± 0.076	Mature	MTOF	Tamil Nadu	Sundarapandian et al. 2014
Mangifera indica	0.53	NS	MTOF	Kerala	Shanavas and Kumar 2003
Mangifera indica	0.601	NS	MTOF	Jhalawar District, Rajasthan	Meghwal et al. 2020
Mangifera indica	0.55	Mature	RTP	Uttara Kannada, Karnataka	Sangeetha et al. 2018
Melia azedarach	0.6	Mature	AT	Punjab	Chauhan et al. 2009
Melia dubia	0.418 - 0.50	Juvenile	AT	Samraj Nagar District, Karnataka	Saravanan 2013
Melia azedarach	0.49	Juvenile	MTOF	Ladhowal, Ludhiana, Punjab	Meena et al. 2014
Melia dubia	0.45-0.60	Juvenile	MTOF	Samraj Nagar District, Karnataka	Saravanan 2014
Melia dubia	0.4	Mature	MTOF	Tamil Nadu and Andhra Pradesh	Marimuthu 2015
Melia azedarach	0.44	NS	UTP	Solan, Himachal Pradesh	Shukla and Mohit 2023
Melia composita	0.505	NS	UTP	Tamil Nadu	Vennila 2021
Melia composita	0.35	NS	UTP	Solan, Himachal Pradesh	Shukla and Mohit 2023
Melia dubia	0.52	NS	UTP	Tamil Nadu	Vennila 2021
Melia dubia	0.38	NS	UTP	Solan, Himachal Pradesh	Shukla and Mohit 2023
Michelia champaca	0.52	Mature	RTP	Uttara Kannada, Karnataka	Sangeetha et al. 2018
Mitragyna parvifolia	0.582	Mature	Mixed TOF	Jhalawar District, Rajasthan	Meghwal et al. 2020
Morus alba	0.54	Mature	MTOF	Solan, Himachal Pradesh	Sharma 2020
Murraya koenigii	0.61	Mature	AT	Saharanpur, Uttar Pradesh	Negi 1963
Murraya exotica	0.83–1.03	Mature	AT	Andamans; Uttar Pradesh	Negi 1963
Neolamarkia cadamba	0.38	NS	UTP	Tamil Nadu	Vennila 2021
Peltophorum pterocarpum	0.56	NS	AT	Kerala	Shanavas and Kumar 2003
Pericopsis mooniana	0.82	Mature	UTP	Nilambur district, Kerala	Anoop et al. 2016
Pinus roxburghii	0.36	Juvenile	UTP	Solan, Himachal Pradesh	Bhat et al. 2016
Pinus roxburghii	0.496	Juvenile	UTP	Dehra Dun, Uttarakhand	Uniyal et al. 2002
Pinus caribaea	0.55	Mature	UTP	Kerala (Idukki)	Anoop et al. 2014
Pinus roxburghii	0.46	Mature	UTP	Solan, Himachal Pradesh	Bhat et al. 2016
Pinus roxburghii	0.531	Mature	UTP	Solan, Himachal Pradesh	Gupta et al. 2016
Pinus roxburghii	0.49	Mature	UTP	Himachal Pradesh	Sharma and Saurabh 2023
Pongamia pinnata	0.59	NS	AT	Kerala	Shanavas and Kumar 2003
Populus deltoides	0.32	Juvenile	AT	Punjab, Haryana, UP, Uttarakhand	Pande 2012; Kothiyal 2012
Populus ciliata	0.38-0.46	Mature	AT	NW Himalayas	Yadav et al. 2022
Populus deltoides	0.45	Mature	AT	Punjab	Chauhan et al. 2009
Populus deltoides	0.448	Mature	AT	Punjab, Haryana, UP, Uttarakhand	Pande 2012; Kothiyal, 2012
Populus euphratica	0.38-0.54	Mature	AT	Plains of Punjab, Ladakh	Yadav et al. 2022
Populus alba	0.46	Mature	AT	Lahaul, Himachal Pradesh	Yadav et al. 2022
Populus nigra	0.46	Mature	AT	Kashmir	Yadav et al. 2022
Populus deltoides	0.41±0.14	Juvenile	UTP	Rudrapur, Uttarakhand	Aziz 2022
Populus deltoides	0.405	Juvenile	UTP	Ludhiana, Punjab	Singh 2021
Populus deltoides	0.333	Juvenile	UTP	Rudrapur, Uttarakhand	Pande 2011
Populus deltoides	0.372	Mature	UTP	Kashmir Valley	Ahmad, Rafeeq 2022
Populus deltoides	0.42	Mature	UTP	Rudrapur, Uttarakhand	Pande 2011
Populus deltoides	0.513	Mature	UTP	Ludhiana, Punjab	Singh 2021
Prosopis juliflora	0.791	Mature	MTOF	Jhalawar District, Rajasthan	Meghwal et al. 2020
Prosopis juliflora	0.736	NS	MTOF	Jalaun district, Uttar Pradesh	Chavan 2016
Pterocarpus marsupium	0.61	NS	AT	Kerala	Shanavas and Kumar 2003
Pterocarpus santalinus	0.14	NS	UTP	Kerala	Hegde et al. 2014
Quercus dilatata	0.76	Mature	MTOF	India (NS)	Rani et al. 2018
Salix spp.	0.76	Mature	AT	Solan, Himachal Pradesh	Sharma et al. 2014
Salix alba var. caerulea	0.498	Mature	UTP	Kashmir Valley	Ahmad and Rafeeq 2022
Samanea saman	0.4	NS	AT	Kerala	Shanavas and Kumar 2003
Santalum album	0.82	NS	AT	Kerala	Shanavas and Kumar 2003
Sapindus laurifolius	0.5	NS	AT	Kerala	Shanavas and Kumar 2003
Schleichera oleosa	0.82	NS	AT	Kerala	Shanavas and Kumar 2003
Shorea assamica	0.62	Mature	UTP	Dehradun	Bhatt and Seema 2016
Shorea robusta	0.75	Mature	UTP	Dehradun	Bhatt and Seema 2016
Shorea roxburghii	0.72	Mature	UTP	Dehradun	Bhatt and Seema 2016
Shorea talura	0.68	Mature	UTP	Dehradun	Bhatt and Seema 2016
Spondias pinnata	0.34	NS	AT	Kerala	Shanavas and Kumar 2003

Tree species	WSG value	Growth stage	Category of TOF	Location	Sources
Sterculia foetida	0.3	NS	AT	Kerala	Shanavas and Kumar 2003
Sterculia alata	0.51	NS	UTP	Tamil Nadu	Vennila 2021
Stereospermum colais	0.48	NS	AT	Kerala	Shanavas and Kumar 2003
Strychnos nux-vomica	0.75	NS	AT	Kerala	Shanavas and Kumar 2003
Swietenia macrophylla	0.53	NS	AT	Kerala	Shanavas and Kumar 2003
Swietenia macrophylla	0.53	Mature	UTP	Palakkad, Kerala	Anoop et al. 2014
Syzygium cumini	0.53	Mature	AT	Punjab	Chauhan et al. 2009
Syzygium cumini	0.61	NS	AT	Kerala	Shanavas and Kumar 2003
Tabernaemontana alternifolia	0.39	NS	AT	Kerala	Shanavas and Kumar 2003
Tamarindus indica	0.8	NS	AT	Kerala	Shanavas and Kumar 2003
Tectona grandis	0.578	Mature	MTOF	NS	Rani et al. 2018
Tectona grandis	0.684 ± 0.094	Mature	MTOF	Tamil Nadu	Sundarapandian et al. 2014
Tectona grandis	0.66	Mature	MTOF	Jhalawar District, Rajasthan	Meghwal et al. 2020
Tectona grandis	0.623-0.691	Mature	MTOF	Kerala	Thulasidas et al. 2012
Tectona grandis	0.56	NS	MTOF	Kerala	Shanavas and Kumar 2003
Tectona grandis	0.56	Mature	UTP	Uttara Kannada, Karnataka	Sangeetha et al. 2018
Tectona grandis	0.444-0.522	Juvenile	UTP	Nilambur, Kerala	Bhat 2000
Tectona grandis	0.619 - 0.681	Juvenile	UTP	Kerala, Karnataka	Bhat and Priya 2004
Tectona grandis	0.553	Juvenile	UTP	Nilambur	Priya and Bhat 1997
Tectona grandis	0.44	Mature	UTP	Kerala	Hegde et al. 2014
Tectona grandis	0.539	Mature	UTP	Nilambur, Kerala	Bhat 2000
Tectona grandis	0.66± 0.01	Mature	UTP	Chandrapur, Maharashtra	Narayanan 2009
Tectona grandis	0.6127	NS	UTP	Chandrapur, Maharashtra	Meena et al. 2016
Tectona grandis	0.655 - 0.665	Mature	UTP	Kerala, Karnataka	Bhat and Priya 2004
Terminalia arjuna	0.688	Mature	AT	Jhalawar District, Rajasthan	Meghwal et al. 2020
Terminalia bellirica	0.45	NS	AT	Kerala	Shanavas and Kumar 2003
Terminalia catappa	0.42	NS	AT	Kerala	Shanavas and Kumar 2003
Terminalia paniculata	0.61	NS	AT	Kerala	Shanavas and Kumar 2003
Terminalia arjuna	0.66	Mature	MTOF	Uttar Pradesh	Kumar et al. 2017
Terminalia arjuna	0.62	Mature	UTP	Uttarakhand	Sharma et al. 2016
Thespesia populnea	0.53	NS	AT	Kerala	Shanavas and Kumar 2003
Toona ciliata	0.34	NS	AT	Kerala	Shanavas and Kumar 2003
Toona ciliata	0.6	Mature	AT	Punjab	Chauhan et al. 2009
Toona ciliata	0.45	Mature	AT	Himachal Pradesh	Dhiman 2018
Trema orientalis	0.3	NS	AT	Kerala	Shanavas and Kumar 2003
Vitex altissima	0.65	NS	AT	Kerala	Shanavas and Kumar 2003
Wrightia tinctoria	0.49	NS	AT	Kerala	Shanavas and Kumar 2003
Xylia xylocarpa	0.72	Mature	AT	NS	Rani et al. 2018
Xylia xylocarpa	0.71	NS	AT	Kerala	Shanavas and Kumar 2003
Zanthoxylum rhetsa	0.34	NS	AT	Kerala	Shanavas and Kumar 2003

NS: Not Specified; **AT:** Agroforestry Trees; **UTP:** Urban Tree Plantations; **RTP:** Rural Tree Plantations; **MTOF:** Mixed Trees Outside Forest

ranged from 0.35 (*M. dubia*) to 0.96 (*H. excelsum*), with juvenile trees ranging from 0.44 (*M. azedarach*) to 0.89–0.95 (*Eucalyptus* sp.). The highest WSG was observed in *H. excelsum*, while the lowest was in *M. dubia*.

DISCUSSION

Wood Specific Gravity exhibits significant variability influenced by genetic, climatic, edaphic, and management factors (Pande and Singh 2005, Varghese et al. 2000). In India, values range from 0.26 (*Bombax ceiba*) to 0.86 (*Acacia catechu*), as their wood composition differences such as lignin concentration (Shanavas and Kumar 2003). Precipitation and WSG relationships are complex with higher densities occuring in dry sites for species like *Tectona grandis* and *Eucalyptus tereticornis* (Thulasidas and Bhat 2012, SriLakshmi and Rao 2004). While geographic variation is evident between plains and Himalayan regions (Heena et al. 2019, Bhat et al. 2016) WSG generally increases with age and diameter (Saravanan et al. 2013, Shukla et al. 2007; Priya and Bhat 1997). The different Categories

of TOF (agroforestry, urban plantations, rural woodlots, and mixed systems) show functional diversity (Shanavas and Kumar 2006, Dhaka and Prajapati 2022, Rani et al. 2018, Sharma et al. 2005). The intraspecific differences of WSG observe with global databases (Zanne et al. 2009) and regional studies (Mayavel et al. 2021, Sangeetha et al. 2018) underscore that local, species-specific WSG data are essential for accurate biomass and carbon accounting, complementing generalized tropical datasets.

CONCLUSION

This inventory of Wood Specific Gravity (WSG) for Trees Outside Forest (TOF) in India demonstrates substantial variability in WSG values across different systems, including agroforestry, urban, rural and mixed environments. The data reveal a wide range, with WSG being influenced by species, growth stage (mature vs. juvenile), and specific site conditions. Using generalized WSG values from global databases for TOF can lead to significant errors in biomass and carbon stock estimations. Therefore, a dedicated, national-level TOF-specific WSG inventory is indispensable for accurate carbon accounting.

ACKNOWLEDGEMENTS

The authors express their deep gratitude to Gokul Global University, particularly the Department of Environmental Sciences and Botany for their support. We also extend our gratitude to the authors of the numerous scientific articles cited in this paper, whose work formed the foundation of this inventory. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author's contributions: S.M Donkeng Voumo designed, arranging the data and drafted the manuscript. N. K. Maurya contributed to revision of first draft. All authors have read and approved the final manuscript.

Conflict of interest: Authors declare that they have no conflict of interest.

REFERENCES

Adutwum, J.O., Sakagami, H., Koga, S. and Matsumura, J. 2023. An application of mixed-effects model to evaluate the role of age and size on radial variation in wood specific gravity in teak (*Tectona grandis*). Journal of Wood Science, 69, 1-15. https://doi.org/10.1186/s10086-023-02080-8

Ahmad, N. and Rafeeq, J. 2022. Cricket bat industry in Kashmir Valley: Wood quality parameters of *Salix alba* var. *caerulea* and *Populus deltoides*. Research Square, 1-10. https://doi.org/10.21203/rs.3.rs-1349342/v1

Al-Sagheer, N.A. and Devi Prasad, A.G. 2010. Variation in wood specific gravity, density and moisture content of *Dipterocarpus indicus* among different populations in Western Ghats of Karnataka, India. International Journal of Applied Agricultural Research, 5, 583-599. https://www.ripublication.com/IJAER/ijaarv5n5_3.pdf

Anonymous. 1952. Methods of determining the specific gravity of wood. United States Department of Agriculture (USDA), Forest Products Laboratory. United States Department of Agriculture (USDA), Madison, Wisconsin, USA.

Anonymous. 2023. India State of Forest Report 2023. Forest Survey of India (FSI), Dehradun, Uttarakhand, India.

Anoop, E.V., Sindhumathi, C.R., Jijeesh, C.M. and Jayasree, C.E. 2016. Radial variation in wood properties of Nedun (*Pericopsis mooniana*), an introduced species to South India. Journal of Tropical Forest Science, 28, 28-34. https://jtropag.kau.in/index.php/ojs2/article/view/304/304

Anoop, E.V., Ajayghosh, V., Nijil, J. and Jijeesh, C. 2014. Evaluation of pulp wood quality of selected tropical pines raised in the High Ranges of Idukki District, Kerala. Journal of Tropical Forest and Environment, 4, 59-66.

Anoop, E.V., Jijeesh, C., Sindhumathi, C. and Jayasree, C. 2014. Wood physical, anatomical and mechanical properties of Big Leaf Mahogany (*Swietenia macrophylla* Roxb) a potential exotic for South India. Research Journal of Agricultural and Forestry Science, 2(8), 7-13. https://www.isca.me/AGRI_FORESTRY/Archive/v2/i8/2.ISCA-RJAFS-2014-037.pdf

Areo, O.S. and Amajek, I. 2022. Evaluation of physical properties of *Blighia sapida* for structural utilization in Nigeria. European Journal of Agriculture and Food Science, 4, 59-66. https://doi.org/10.24018/ejfood.2022.4.2.477

Aziz, M. 2022. Variations in wood traits and specific gravity in male clone of *Populus deltoides* Bartr. Ex Marsh. Research Square, 1-10. http://dx.doi.org/10.21203/rs.3.rs-2258926/v1

Babita, S., Sharma, B.K., Baniya, C.B. and Yadav, R.K. 2024. Tree species richness and phytomass carbon stock along the urban-rural gradient in trees outside forests of Kathmandu valley, Nepal. Arboricultural Journal, 46(1), 36-56. https://doi.org/10.1080/03071375.2023.2241812

Baqir, M., Kothari, R. and Singh, R.P. 2017. Characterization and ranking of subtropical trees in a rural plantation forest of Uttar Pradesh, India, as fuel wood using fuel wood value index (FVI). Environment, Development and

Sustainability, 1-14. https://doi.org/10.1007/s10668-017-0057-z

Bessa, F., Sousa, V., Quilhó, T. and Pereira, H. 2022. An integrated similarity analysis of anatomical and physical wood properties of tropical species from India, Mozambique, and East Timor. Forests, 13, 1675. https://doi.org/10.3390/f13101675

Bhandari, M.S., Dabral, A., Maikhuri, S., Bisht, A., Thapliyal, G., Kant, R. M., Rajendra, K., Kumar, D. and Rana, V. 2023. Genetic evaluation and characterization of anatomical and physicochemical properties in *Grevillea robusta*: An alternative commercial agroforestry species. Journal of Indian Academy of Wood Science, 20, 1-15. https://doi.org/10.1007/s13196-023-00316

Bhat, K.M. 2000. Quality of teak wood from managed tropical plantations. With a special mention to Indian plantations. Bois et Forêts des Tropiques, 263, 5-16. https://revues.cirad.fr/index.php/BFT/article/view/20060/19819

Bhat, K.M., Thulasidas, P.K., Florence, E.J. and Jayaraman, K. 2005. Wood durability of home-garden teak against brown-rot and white-rot fungi. Trees, 19, 654-660. https://10.1007/s00468-005-0429-0

Bhat, K. and Priya, P. 2004. Influence of provenance variation on wood properties of Teak from the Western Ghat region in India. IAWA Journal, 25, 273-282. https://doi.org/10.1163/22941932-20040028

Bhat, S.S., Singh, N.B., Sankhyan, H.P. and Sharma, K.R. 2016. Variability studies for needle and wood traits of different half sib progenies of *Pinus roxburghii* Sargent. Physiology and Molecular Biology of Plants, 22, 231-239. https://doi.org/10.1007/s12298-016-0358-y

Bhatt, S. 2016. Comparative studies on wood quality parameters of exotic and native species of *Shorea* Roxb. ex C.F. Gaertn. Ph.D. Thesis, Dr. Yashwant Singh Parmar University of Horticulture & Forestry, Solan, India. 190 pages.

Borpuzari, P.P. and Chand, T. 2021. Screening of promising clones of Gmelina arborea Roxb. at gene bank with higher productivity: a multipurpose tree species. Plants and Environment, 3, 102-106. https://doi.org/10.22271/2582-3744.2021.dec.102

Chauhan, K. 2016. Studies on properties of coniferous woods available in the markets of Himachal Pradesh. Ph.D. Thesis, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, India. 180 pages.

Chauhan, S.K., Gupta, N., Ritu, Yadav, S. and Chauhan, R. 2009. Biomass and carbon allocation in different parts of agroforestry tree species. Indian Forester, 135, 985-993.

Chavan, S.B. 2016. Fuelwood characteristics of selected tree species from Bundelkhand region of Central India. Ecology, Environment and Conservation, 22, S87–S95.

Chave, J., Muller-Landau, H.C., Baker, T.R., Easdale, T.A., ter Stege, H. and Webb, C.O. 2006. Regional and phylogenetic variation of wood density across 2456 Neotropical tree species. Ecological Applications, 16, 2356-2367. https://doi.org/10.1890/1051-0761(2006)016[2356:RAPVOW]2.0.CO;2

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., Duque, A., Eid, T., Fearnside, P.M., Goodman, R.C., Henry, M., Martínez-Yrízar, A., Mugasha, W.A., Muller-Landau, H.C., Mencuccini, M., Nelson, B.W., Ngomanda, A., Nogueira, E.M., Ortiz-Malavassi, E., Pélissier, R., Ploton, P., Ryan, C.M., Saldarriaga, J.G. and Vieilledent, G.. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biology, 20, 3177-3190. https://doi.org/10.1111/gcb.12629

Chen, S., Weng, Q., Li, F., Li, M., Zhou, C. and Gan, S. 2018. Genetic parameters for growth and wood chemical properties in *Eucalyptus urophylla* × *E. tereticornis* hybrids. Annals of Forest Science, 75, 16. https://doi.org/10.1007/s13595-018-0694-x

Choudhary, S. 2022. Variation in physico-chemical wood properties of *Dalbergia sissoo* Roxb. ex-DC. in Rajasthan. M.Sc. Thesis, College of Horticulture and Forestry, Jhalrapatan, Agriculture University, Kota, India.

Chowdhury, M.Q., Ishiguri, F., Iizuka, K., Hiraiwa, T., Matsumoto, K., Takashima, Y. et al. 2009. Wood property variation in *Acacia auriculiformis* growing in Bangladesh. Wood and Fiber Science, 41, 359-365. https://wfs.swst.org/index.php/wfs/article/view/1230/1230

Chowdhury, M.Q., Khan, M.R. and Mehedi, M.A. 2013. Wood density variation in four plantation species growing in Bangladesh. Journal of Indian Academy of Wood Science, 10, 124-130. https://doi.org/10.1007/s13196-013-0090-y

Dasgupta, M.G., Abdul Bari, M.P., Shanmugavel, S., Dharanishanthi, V., Muthupandi, M., Kumar, N., Chauhan, S.S., Kalaivanan, J., Mohan, H., Krutovsky, K.V. and Rajasugunasekar, D. 2021. Targeted re-sequencing and genome-wide association analysis for wood property traits in breeding population of *Eucalyptus tereticornis* × *E. grandis*. Genomics, 113, 4276–4292. https://doi.org/10.1016/j.ygeno.2021.11.013

Dhaka, R.K. and Prajapati, D.R. 2022. Growth attributes and wood properties of lesser-grown agroforestry tree species in the semi-arid zone for quality pulp and paper production. Journal of Agriculture and Ecology, 13, 150-159. https://doi.org/10.53911/JAE.2022.13115

Dhillon, G.P., Sandhu, J.S. and Singh, P. 2020. Variation among poplar (*Populus deltoides* Bartr.) clones for growth, wood traits and tolerance to leaf spot diseases. Current Agriculture Research Journal, 8, 128-136. https://doi.org/10.12944/CARJ.8.2.08

Dhiman, B. 2018. Physico-chemical evaluation of wood of Toon (*Toona ciliata* M. Roem.) provenances from Himachal Pradesh. Ph.D. Thesis, Dr. Yashwant Singh Parmar University of Horticulture & Forestry, Solan, India. 170 pages.

Ghosh, S.S. and Purkayastha, S.K. 1963. Indian Woods: Their identification, properties and uses. Vol. II. Survey of India Offices, Dehra Dun, Delhi, India.

Gupta, H., Sharma, K.R. and Meena, R.K. 2016. Effect of *Lantana camara* L extract on specific gravity of wood species. International Journal of Farm Sciences, 6, 277-280.

Heena, Dutt, B., Sharma, K.R. and Kumar, R. 2019. Variation in specific gravity of wood of *Quercus leucotrichophora*

A. Camus (Banoak) from different provenances in Himachal Pradesh. International Journal of Chemical Studies, 7, 1335-1337. https://www.chemijournal.com/archives/2019/vol7issue1/PartW/7-1-270-845.pdf

Hegde, H.T., Kalkoor, M.A., Jha, S.K. and Thakur, N.S. 2014. Evaluation of variation in physical properties of wood among some tropical tree species of South India. Indian Forester, 140, 70-75.

Hossain, M., Mondal, S., Banerjee, A., Lekshmi, N.M., Manojkumar, B. 2018. Changes in the specific gravity in rubber wood treated with cashew nut shell liquid and nano based wood preservatives. International Journal of Current Microbiology and Applied Sciences, 7, 720-723. https://doi.org/10.20546/ijcmas.2018.710.079

Huse, S., Gunaga, R., Sinha, S. and Behera, L. 2024. Genetic variation in wood mechanical properties among *Eucalyptus* clones. Indian Journal of Ecology, 51, 272-276. https://doi.org/10.55362/IJE/2024/4229

Jeevan, K., Shilpa, G., Manjusha, K., Muthukumar, A. and Muthuchamy, M. 2025. Comparison of carbon stock potential of different trees outside forest' systems of Palakkad District, Kerala: A step towards climate change mitigation. Land Degradation and Development, 36(3), 885-899. https://dx.doi.org/10.1002/ldr.5400

Kamalakannan, R., Ganapathy, S.P., Shukla, S.R., Varghese, M. and Jayasree, C.E. 2023. Evaluation of growth and wood traits in *Eucalyptus camaldulensis* and interspecific Eucalypt hybrid clones raised at three diverse sites in Southern India. Journal of Forest and Environmental Science, 39, 27-39. https://doi.org/10.7747/JFES.2023.39.1.27

Kantariya, N.M. and Sinha, S.K. 2023. Wood properties and utilization of pollard shoots of Indian Tulip Tree (*Thespesia populnea* (L.) Sol. ex Corrêa). Indian Journal of Ecology, 50, 980-983. https://doi.org/10.55362/IJE/2023/3999

Kothiyal, V. 2012. Studies on wood quality of Poplars in India. ENVIS Forestry Bulletin, 12, 123-131. https://frienvis.nic.in/WriteReadData/UserFiles/file/Content-Page/Vol-12-No-1/Vol-12-1-11-Studies-on-wood-quality-of-poplar.pdf

Kumar, H., Lal, S.B. and Wani, A.M. 2017. Correlation studies for morphological and biomass traits in half sib families of *Terminalia arjuna* (L.). Current World Environment, 12, 345-354. https://doi.org/10.12944/CWE.12.2.18

Kushwaha, A.K. 2022. Effect of wood density on above-ground biomass while measuring the mango trees. Indian Journal of Hill Farming, 35, 107-119. https://doi.org/10.56678/iahr-spl2022.13

Manikandan, S., Udayakumar, M. and Sekar, T. 2019. Wood density and physiognomy of tree species in Pachaimalai hills of Southern Eastern Ghats, Tamil Nadu, India. International Journal of Scientific Research and Review, 8(3), 479-491.

Mascarenhas, A.R., Sccoti, M.S., de Melo, R.R., de Oliveira Corrêa, F.L., de Souza, E.F. and Pimenta, A.S. 2021. Physico-mechanical properties of the wood of freijó, *Cordia goeldiana* (Boraginaceae), produced in a multi-stratified agroforestry system in the southwestern Amazon. Acta Amazonica, 51, 171-180. https://doi.org/10.1590/1809-4392202003001

Mayavel, A., Esakkiammal, S., Chitra, P., Binodh, A.K. and Kamalakannan, R. 2021. Genetic analysis for growth and wood fiber properties in second generation clones of *Acacia auriculiformis*. Electronic Journal of Plant Breeding, 12, 490-498. https://doi.org/10.37992/2021.1202.069

Meena, H., Sharma, R. and Kumar, A. 2014. Progeny evaluation of *Melia azedarach* (Linn.) for leaf senescence, fruit characters and wood specific gravity. Indian Forester, 140, 891-895.

Meena, R.K. and Dutt, B. 2022. Effect of plant extracts on specific gravity of *Pinus roxburghii* Sargent wood. Environment and Ecology, 40, 1150-1153. https://environmentandecology.com/wp-content/uploads/2024/06/MS17-3.pdf

Meena, R.K. and Nimkar, A.U. 2016. Genotypic, phenotypic and environmental correlation coefficient of physico-chemical properties of wood of different provenances of teak (*Tectona grandis* L.). Environment and Ecology, 34, 828-831.

Meena, R.K., Nimkar, A.U. and Gupta, H. 2016. Variation in bark percentage, specific gravity of wood and fibers length in different provenances of teak (*Tectona grandis* L.) wood. Environment and Ecology, 34, 1781-1784.

Meghwal, S., Upadhyay, K., Nagar, B., Vijayan, A.S., Pulpayil, N. and Sharma, S.K. 2020. Wood specific gravity of important hardwood tree species of Jhalawar District. International Journal of Chemical Studies, 8, 267-269. https://doi.org/10.22271/chemi.2020.v8.i6d.11167

Miah, M.D. and Islam, G.A. 2020. Reckoning physical properties of firewood with its preference by the rural households in a selected village of Narsingdi district of Bangladesh. Environmental Earth and Ecology, 4, 15-30. https://doi.org/10.24051/eee/122129

Mihriemate, R.L., Singh, B. and Mailappa, A.S. 2020. Carbon stock of prevailing land use systems under East Siang District, Arunachal Pradesh, India. International Journal of Current Microbiology and Applied Sciences, 9, 2568-2875. https://doi.org/10.20546/ijcmas.2020.906.312

Moya, R. and Perez, D. 2008. Effects of physical and chemical soil properties on physical wood characteristics of *Tectona grandis* plantations in Costa Rica. Journal of Tropical Forest Science, 20, 248-257. https://www.jstor.org/stable/23616701

Moya, R., Bond, B. and Quesada, H. 2014. A review of heartwood properties of *Tectona grandis* trees from fast-growth plantations. Wood Science and Technology, 48, 411-433. https://doi.org/10.1007/s00226-014-0618-3

Nagar, B., Rawat, S., Pandey, R. and Kumar, M. 2021. Variation in specific gravity and carbon proportion of agroforestry tree species of Himalaya. Environmental Challenges, 4, 100156. https://doi.org/10.1016/j.envc.2021.100156

Narayanan, C.C. 2009. Inheritance Pattern of Growth and Wood Traits in Teak (*Tectona grandis* L.f.). Silvae Genetica, 58, 97-101. https://doi.org/10.1515/sg-2009-0013

Nayak, S., Sahoo, U.K., Thangjam, U. and Garnayak, L.M.

2020. Provenance variations of morphometric traits and oil contents of *Madhuca latifolia* Macbride in Odisha: Implication for tree improvement. Journal of Experimental Biology and Agricultural Sciences, 8, 224-232. https://doi.org/10.18006/2020.8(3).224.232

Negi, B.S. 1963. Indian Woods: Their identification, properties and uses. Vol. II. Survey of India Offices, Dehra Dun, Delhi, India.

Olayanu, C.M., Omole, A.O., Adeyemo, S.M., Majekobaje, A.R. and Areo, O.S. 2022. Evaluation of selected physical properties of *Blighia sapida* K. Koenig wood. European Journal of Agriculture and Food Science, 4, 58-65. https://doi.org/10.24018/ejfood.2022.4.2.477

Pande, P.K. 2011. Variation in wood properties and growth in some clones of *Populus deltoides* Bartr. ex-Marsh. American Journal of Plant Sciences, 2, 644-649. https://doi.org/10.4236/ajps.2011.25076

Pande, P.K. 2012. Status of anatomy and physical properties of wood in poplars in India. ENVIS Forestry Bulletin, 12, 132-150. https://frienvis.nic.in/WriteReadData/UserFiles/file/Content-Page/Vol-12-No-1/Vol-12-1-12-Status-of-anatomy-and-physical-properties-of-wood-in-poplars.pdf

Pande, P.K. and Singh, M. 2005. Inter-clonal, intra-clonal, and single tree variations of wood anatomical properties and specific gravity of clonal ramets of *Dalbergia sissoo* Roxb. Wood Science and Technology, 39, 351-366. https://doi.org/10.1007/s00226-004-0273-1

Parveen, A.B., Muthupandi, M., Kumar, N., Chauhan, S.S., Vellaichamy, P., Senthamilselvam, S. et al. 2021. Quantitative genetic analysis of wood property traits in biparental population of *Eucalyptus camaldulensis* x *E. tereticornis*. Journal of Genetics, 100, 46. https://doi.org/10.1007/s12041-021-01299-x

Patel, R.H., Sinha, S.K., Nayak, D. and Patel, A.K. 2022. Effect of age on the growth and physical properties of *Ailanthus excelsa* Roxb. The Pharma Innovation Journal, 11(1), 767-769. https://www.thepharmajournal.com/archives/2022/vol11issue1S/PartL/S-11-1-151-246.pdf

Pati, P.K., Kaushik, P., Khan, M.L. and Khare, P.K. 2022. Wood Specific Gravity in Indian Forests: A Review. International Journal of Ecology and Environmental Sciences, 48, 143-164. https://doi.org/10.55863/ijees.2022.0111

Pati, P.K., Kaushik, P., Maurya, D., Adhikari, C., Bishwas, A.J., Khan, M.L. and Khare, P.K. 2024. Evaluating the role of roadside vegetation in atmospheric carbon dioxide mitigation: a case study. Arboricultural Journal, 46, 97-119. https://doi.org/10.1080/03071375.2023.2233868

Pati, P.K., Kaushik, P., Khan, M.L. and Khare, P.K. 2025. Inventory of wood specific gravity for Indian forests. Trees, Forests and People, 19, 100775. https://doi.org/10.1016/j.tfp.2025.100775

Pillai, P.K., Pandalai, R.C., Dhamodaran, T.K. and Sankaran, K.V. 2013. Wood density and heartwood proportion in Eucalyptus trees from intensively-managed short-rotation plantations in Kerala, India. Journal of Tropical Forest Science, 25, 220-227. https://jtfs.frim.gov.my/jtfs/article/view/385/286

Priya, P.B. and Bhat, K. 1997. Wood anatomical changes in juvenile teak due to insect defoliation. IAWA Journal, 18, 311-317. https://doi.org/10.1163/22941932-90001498

Ramanan, S.S., Kunhamu, T.K., Anoop, E.V. and George, A.K. 2018. Does stand thinning influence wood physical properties? An investigation in a tropical hardwood, *Acacia mangium* Willd. Journal of Tropical Agriculture, 56(2), 137-144. https://jtropag.kau.in/index.php/ojs2/article/view/572/473

Ramesh, M. and Rao, B.R. 2016. Carbon stocks of trees outside forest in Kurnool district, Andhra Pradesh, India. Indian Journal of Forestry, 39, 1-4. https://doi.org/10.54207/bsmps1000-2016-N3O143

Rani, A., Singh, J. and Singh, T. 2017. An experimental characterization of physical properties of timber woods. Materials Science and Nanotechnology, 1, 41-45. https://doi.org/10.15406/msnan.2017.01.00009

Rani, A., Singh, J. and Singh, T.P. 2018. A brief review on physical and mechanical properties of Indian subcontinent timber and their measurable characteristics. SF Journal of Material Research Letters, 2, 1-5.

Raveena, Dutt, B., Kumar, R., Sharma, Y.P. and Pingale, A. 2024. Effect of heat treatment on specific gravity, water absorption, and volumetric swelling of *Acrocarpus fraxinifolius* wood. International Journal of Advanced Biochemistry Research, 8(4), 260-267. https://doi.org/10.33545/26174693.2024.v8.i4Sd.958

Reyes, G., Brown, S., Chapman, J. and Lugo, A.E. 1992. Wood densities of tropical tree species. U.S. Department of Agriculture, Forest Service, Institute of Tropical Forestry, Puerto Rico.

Rigg-Aguilar, P. and Moya, R. 2018. Properties of juvenile wood from 7-year-old *Cedrela odorata* trees of two different populations growing in agroforestry systems with Theobroma cacao. Maderas Ciencia y Tecnología, 24, e2411485. https://doi.org/10.21829/myb.2018.2411485

Sahoo, R.K. 2018. Studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood from two agro-climatic zones of Odisha. M.Sc. Thesis, Orissa University of Agriculture and Technology, Orissa, India.

Sahoo, R.K., Nayak, S. and Rout, S. 2020. Variability in physical properties of *Eucalyptus* hybrid wood. Indian Journal of Pure and Applied Biosciences, 8, 119-123. https://doi.org/10.18782/2582-2845.8182

Saini, P., Kumari, A., Jha, S. and Chauhan, S. 2024. Variation in physico-chemical properties of *Diospyros montana* Roxb. in Himachal Pradesh. Indian Journal of Ecology, 51, 1150-1155. https://doi.org/10.55362/IJE/2024/4369

Sangeetha, H., Poonia, P.K. and Hanumantha, M. 2018. Moisture related properties of different plantation grown tree species in Western Ghat region. Progressive Research, 13(4), 311-313.

Sanwo, S.K. 1986. Intra-tree variations of strength properties in plantation grown Teak (*Tectona grandis* L.F) and techniques for their systematic sampling. Oxford Forestry Institute, Department of Plant Sciences, Oxford, UK.

Saravanan, V.P., Parthiban, K.T., Kumar, P. and Mariamutthu, P. 2013. Wood characterization studies on *Melia dubia* cav. for pulp and paper industry at different age gradation.

Research Journal of Recent Sciences, 2, 183-188. https://www.isca.me/rjrs/archive/v2/iISC-2012/33.ISCA-ISC-2012-1AFS-26.pdf

Saravanan, V.P. 2014. Comparative study of wood physical and mechanical properties of *Melia dubia* with *Tectona grandis* at different age gradation. Research Journal of Recent Sciences, 3, 256-263. https://www.isca.in/rjrs/archive/v3/iISC-2013/47.ISCA-ISC-2013-1AFS-36.php

Sarkar, B.C. and Dey, A.N. 2021. Wood specific gravity of some tree species in Terai region of West Bengal, India. Journal of Agricultural Technology, 8, 67-71. https://www.cobacas.org.in/wp-content/uploads/2022/09/Final-JAT-Vol-8-1-2-2021.pdf

Schnell, S., Altrell, D., Ståhl, G. and Kleinn, C. 2015. The contribution of trees outside forests to national tree biomass and carbon stocks – A comparative study across three continents. Environmental Monitoring and Assessment, 187, 419. https://doi.org/10.1007/s10661-014-4197-4

Schnell, S., Kleinn, C. and Ståhl, G. 2015. Monitoring trees outside forests: A review. Environmental Monitoring and Assessment, 187, 600. https://doi.org/10.1007/s10661-015-4817-7

Selvan, R.T., Parthiban, K.T. and Khanna, S.U. 2017. Physio-chemical properties of bamboo genetic resources at various age gradations. International Journal of Current Microbiology and Applied Sciences, 6, 1671-1681. https://doi.org/10.20546/ijcmas.2017.609.205

Shanavas, A. and Kumar, B.M. 2003. Fuelwood characteristics of tree species in homegardens of Kerala, India. Agroforestry Systems, 58, 11-24. https://doi.org/10.1023/A:1025450407545

Shanavas, A. and Kumar, B.M. 2006. Physical and mechanical properties of three agroforestry tree species from Kerala, India. Journal of Tropical Agriculture, 44, 23-30. https://jtropag.kau.in/index.php/ojs2/article/view/146/146

Sharma, K.R., Kilemwa, A.M., Singh, N. and Lekha, C. 2014. Variability in wood properties of promising willow clones. International Journal of Lignocellulosic Products, 1, 82-92. https://ijlp.gau.ac.ir/article_1926_b4ea7caeefa3119348ca6720844dce65.pdf

Sharma, S. 2023. Effect of chemical stimulants on oleoresin production and wood quality of *Pinus roxburghii* Sargent. Ph.D. Thesis, Dr. Yashwant Singh Parmar University of Horticulture & Forestry, Solan, India.

Sharma, S.K., Rao, R., Shukla, S.R., Kumar, P., Sudheendra, R. and Sujatha, M. 2005. Wood quality of coppiced *Eucalyptus tereticornis* for value addition. IAWA Journal, 26, 137-147. https://doi.org/10.1163/22941932-20050013

Sharma, S.K., Shukla, S.R., Shashikala, S. and Sri Poornima, V. 2015. Axial variations in anatomical properties and basic density of *Eucalypt urograndis* hybrid (*Eucalyptus grandis* × *E. urophylla*) clones. Journal of Forestry Research, 26, 643-650. https://doi.org/10.1007/s11676-015-0071-6

Sharma, V. 2020. Evaluation of *Morus alba* L. clones for morphometric and wood characteristics. Ph.D. Thesis, Dr. Yashwant Singh Parmar University of Horticulture & Forestry, Solan, India.

Sharma, V., Kumar, R., Dutt, B. and Attri, V. 2002. Influence of heat treatment on chemical and mechanical properties of *Toona ciliata* M. Roem. Materials Science Research India, 19, 44-53. https://doi.org/10.13005/msri/1901

Sharma, V., Patel, P.K. and Kumar, D. 2016. Estimation of standing state biomass and carbon sequestration potential of multipurpose tree species at Mohand Range, Dehradun Forest Division, Uttarakhand. Indian Forester, 142, 1087-1092.

Sheikh, M.A., Kumar, M. and Bhat, J.A. 2011. Wood specific gravity of some tree species in the Garhwal Himalayas, India. Forest Studies in China, 13, 225-230. https://doi.org/10.1007/s11632-011-0310-8

Shrestha, H.L., Rai, A. and Dhakal, P. 2019. Assessment of above ground biomass of trees outside forest (TOF) in the context of climate change. Journal of Ecology and Natural Resources, 4, 1-9. https://doi.org/10.23880/jenr 16000186

Shukla, M. 2023. Studies on wood quality characteristics of *Melia* species. Ph.D. Thesis, Dr. Yashwant Singh Parmar University of Horticulture & Forestry, Solan, India.

Shukla, S.R. 2019. Evaluation of dimensional stability, surface roughness, colour, flexural properties and decay resistance of thermally modified *Acacia auriculiformis*. Maderas Ciencia y Tecnología, 21, 433-446. https://doi.org/10.4067/S0718-221X2019005000401

Shukla, S., Rao, R., Sharma, S., Kumar, P., Sudheendra, R. and Shashikala, S. 2007. Physical and mechanical properties of plantation-grown *Acacia auriculiformis* of three different ages. Australian Forestry, 70, 86-92. https://doi.org/10.1080/00049158.2007.10675007

Singh, L. 2021. Variability and correlation studies in poplar (*Populus deltoides* Bartr. Ex Marsh) clones for growth and quality traits. Ph.D. Thesis, Punjab Agricultural University, Punjab, India.

Smith, D.M. 1954. Maximum moisture content method for determining specific gravity of small wood samples. United States Department of Agriculture, Forest Service, Forest Products Laboratory Report No. 2014, Madison, Wisconsin, USA.

SriLakshmi, S. and Rao, R. 2004. Radial variation in specific gravity of *Eucalyptus tereticornis* Sm. clones. Journal of Indian Academy of Wood Science, 1, 37-43.

Sudrajat, D.J., Ayyasy, Y., Siregar, I.Z. and Karlinasari, L. 2021. Mahogany (*Swietenia macrophylla* King.) as urban tree: Tree growth and wood quality variation in a progeny test. IOP Conference Series: Earth and Environmental Science, 918, 012042. https://doi.org/10.1088/1755-1315/918/1/012042

Sundarapandian, S.M., Mageswaran, K., Gandhi, D.S. and Dar, J.A. 2014. Impact of Thane Cyclone on tree damage in Pondicherry University Campus, Puducherry, India. Current World Environment, 9, 287-300. https://doi.org/10.12944/CWE.9.2.09

Sunny, P.P., Anoop, E., Vidyasagaran, K. and Vishnu, B. 2020. Variation in physical properties of *Artocarpus heterophyllus* Lam. wood grown in Thrissur district, Kerala. Journal of Pharmacognosy and Phytochemistry, 9(5), 219-225. https://www.phytojournal.com/archives/2020/vol9issue5/PartD/9-4-366-527.pdf

Sunny, P.P., Dutt, B., Sharma, K.R., Dhiman, B. and Sumthane, Y.Y. 2019. Wood variation in physico-mechanical properties of *Dalbergia sissoo* Roxb. ex-DC. from local markets of Himachal Pradesh. Journal of Tropical Agriculture, 57(1), 17-26. https://jtropag.kau.in/index.php/ojs2/article/view/650/495

Sunny, P.P., Dutt, B., Sumthane, Y.Y., Dhiman, B. and Panwar, H. 2020. Correlation and regression analysis of wood properties of *Dalbergia sissoo* Roxb. ex-DC. procured from local markets of Himachal Pradesh, India. Journal of Pharmacognosy and Phytochemistry, 9(4), 3414-3417. https://www.phytojournal.com/archives/2020/vol9issue4/PartAI/9-4-367-642.pdf

Sunny, P.P., Anoop, E.V. and Vidyasagaran, K. 2020. Wood variation in chemical properties of *Artocarpus heterophyllus* Lam. grown in Thrissur district, Kerala. International Journal of Chemical Studies, 8, 2216-2220. https://doi.org/10.22271/chemi.2020.v8.i3af.9540

Sunny, P.P., Kunhamu, T.K., Santhoshkumar, A.V. and Hrideek, T.K. 2021. Variation in physical properties of *Artocarpus heterophyllus* Lam. wood grown in Thrissur district, Kerala. Journal of Pharmacognosy and Phytochemistry, 9(5), 219-225. https://www.phytojournal.com/archives/2020/vol9issue5/PartD/9-4-366-527.pdf

Sylvain Meinrad, D.V. and Narendra Kumar, M. 2024. Methods for assessment biomass and carbon stock of Tamarind tree (*Tamarindus indica*): A comprehensive review. IRASS Journal of Multidisciplinary Studies, 1, 11-17. https://irasspublisher.com/assets/articles/1734700623.pdf

Thulasidas, P.K. and Bhat, K.M. 2012. Mechanical properties and wood structure characteristics of 35-year-old home-garden teak from wet and dry localities of Kerala, India in comparison with plantation teak. Journal of Indian Academy of Wood Science, 9, 23-32. https://doi.org/10.1007/s13196-012-0062-7

Uniyal, D., Verma, S., Sharma, S. and Sharma, V. 2002. Provenance variation in the specific gravity of wood of Chir Pine (*Pinus roxburghii* Sarg.). Indian Forester, 128, 1295-1299.

Varghese, M., Nicodemus, A., Ramteke, P., Anbazhagi, G., Bennet, S. and Subramanian, K. 2000. Variation in growth and wood traits among nine populations of teak in Peninsular India. Silvae Genetica, 49, 201-205.

Veeranjaneyullu, D., Shareef, M., Jyothi, K., Devi, A.S. and Suneela, M. 2023. Estimation of carbon stock of the trees in the herbal garden of Telangana State Medicinal Plant Board, Hyderabad, India. Indian Journal of Ecology, 50, 1046-1051. https://doi.org/10.55362/IJE/2023/4011

Vennila, S. 2021. Screening of indigenous pulpwood for paper production. International Journal of Chemical Studies, 9, 1059-1064. https://doi.org/10.22271/chemi.2021.v9.i2o.11961

Vishnu, R., Anoop, E.V., Warrier, K.C. and Anish, M.C. 2018. Genetic divergence for growth and wood parameters in different clones of *Casuarina equisetifolia*. Journal of Tropical Forest Science, 30, 615-621. https://doi.org/10.26525/jtfs2018.30.4.615621

Warrier, K.C., Abinaya, R., Gireesan, K. and Jayakumar, M. 2023. Wood fibre properties and genetic divergence in *Haldina cordifolia* (Roxb.) Ridsdale. International Journal of Environment and Climate Change, 13, 617-627. https://doi.org/10.22271/2582-3744.2021.dec.102

Yadav, R., Kumar, D. and Ansari, T. 2022. Wood fibre characteristics of underutilized poplar species and comparison with *P. deltoides* in terms of their pulp and paper quality. Journal of Biomedical Research and Environmental Sciences, 3, 1433-1439. https://doi.org/10.37871/jbres1617

Zanne, A.E., Lopez-Gonzalez, G., Coomes, D.A., Ilic, J., Jansen, S., Lewis, S.L. and Chave, J. 2009. Data from: Towards a worldwide wood economics spectrum. Dryad Digital Repository. Ecology Letters, 12, 351-366. https://doi.org/10.1111/j.1461-0248.2009.01285.x

Received: 17th July 2025
Accepted:3rd December 2025