Chapter 3
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The flow diagram of systematic methodologies for the present investigation has been presented in Figure 3.1.

Figure 3.1: Flow diagram of systematic methodologies
3.1 Study site

The sites selected for the study were the forests and different localities of the state of Arunachal Pradesh, located in the North-East India (Figure 3.2). The state is situated between 26° 28' and 29° 30' North latitudes and 91° 30' and 97° 30' East longitudes. Bio-geographically it is situated in the eastern Himalayan province, the richest bio-geographical province of the Himalayan zone. The entire territory is a complex hill system with varying elevations ranging from 50 m in the foothills and gradually ascending to about 7000 m, traversed throughout by a number of rivers and rivulets [1].

![Map showing the location of study site](image)

**Figure 3.2: Map showing the location of study site**

The climate of Arunachal Pradesh is humid to per humid subtropical, characterized by the high rainfall and high humidity of the sub-Himalayan belt. However, a temperate climate prevails in the lower Himalayan region and the greater
Himalayan region is perpetually covered with snow. The average annual rainfall varies from 1380 to 5000 mm. The minimum temperature is around 0°C in winter months in the Bomdila and Twang areas, while it rises to 35°C during summer months in the Namsai and Tezu areas of Lohit district. The mean annual air temperature is 23.8°C in the plains and 16.2°C in the hilly regions [2]. Different kinds of soils are present in Arunachal Pradesh and predominating four soil orders are Inceptisols, Entisols, Ultisols and Alfisols [2]. Details of geographical location, physiography and characteristics of soils under different agro-ecological sub regions of the state are presented in Annexure I. The vegetation of Arunachal Pradesh falls under four broad climatic categories and can be classified into five broad forest types with a sixth type of secondary forests [1]. Forest distribution in different districts of Arunachal Pradesh according to the types along with the state map is presented in Annexure II.

3.2 Selection of tree species

A total of twenty six (26) indigenous hardwood tree species grown in their natural habitats were collected from the forests and different localities of Arunachal Pradesh during the months of November and December, 2010. On the basis of the consideration of local user’s preference for the best fuelwood species among the tree species grown in a particular locality, the tree species were identified and selected for the present study. The species were Castanopsis indica, Macaranga pustulata, Dysoxylum binectariferum, Bridelia retusa, Myrsine semiserrata, Celtis australis, Dysoxylum procerum, Terminalia myriocarpa, Syzygium cerasoides, Kydia calycina, Mallotus phillipensis, Albizia odoratissima, Litsea polyantha, Mimusops elengi, Bauhinia variegata, Premna integrifolia, Talaula hodgsonii, Pterospermum acerifolium, Vitex altissima, Schima wallichii, Alnus nepalensis, Qurcus lanata, Qurcus leucotrichophora, Rhododendron arboreum, Myrica esculenta and Ehretia acuminata.
3.3. Characteristics of the tree species

Characteristics of the selected tree species on the basis of their botanical description, wood quality, availability etc. are described elsewhere [1, 3-7]. Availability of the selected tree species in different forest types and districts of Arunachal Pradesh is presented in Annexure-II. Botanical descriptions of the tree species are presented below:

a) Botanical name: *Castanopsis indica* DC.

Vernacular name: Hinguri

Family: Fagaceae

![Figure 3.3(a): Castanopsis indica](image)

A middle sized or large tree. Bark grayish, warty, somewhat deeply fissured vertically, with exfoliating scales, 1.27cm thick. Leaves 7.62-19.05 by 3.30-7.62cm elliptic-oblong or oblong-lanceolate, acute or acuminate, spinous-serrate, coriaceous, glabrous above, rusty-tomentose beneath; lateral nerves 14-20 on either half, conspicuous beneath, sub parallel; midrib depressed above and pubescent; base
rounded or obtuse, occasionally unequal sided; petiole 0.76-1.27 cm long. Male spikes in lax panicles, longer than the leaves, stamens 12. Female spikes axillary, solitary. Flowers solitary. Ripe involucers 2.54-3.81 cm in diameter, thin walled, densely covered with straight unequal radiating subulate pubescent spines, the longest above 1.27 cm long. Nut ovoid 0.76-1.27 cm. Wood hard, grayish white, coarse grained, durable, used as firewood, for making charcoal etc.

b) Botanical name: Macaranga pustulata King ex Hook.

Vernacular name: Jaglo, Moralia

Family: Euphorbiaceae

Figure 3.3 (b): Macaranga pustulata

Middle sized evergreen tree, often gregarious; young parts rusty-tomentose; stem fluted. Bark grayish or grayish brown, with horizontal wrinkles, 0.76 cm thick. Leaves peltate, 7.62-30.48 by 6.35-25.4 cm, broad-ovate, acuminate, denticulate or entire, sub-coriaceous, above, glaucescent and dotted with numerous red minute orbicular glands beneath; basal nerves 57, radiating; lateral nerves 10-12 on either side
of midrib, slightly arcuate; base rounded, truncate or cordate; petiole 5.08-20.32 cm long; stipules small fugacious. Male panicles slender, 10.16-15.24 cm long, each bract subtending a cluster of 5-8 pubescent flowers; calyx-segments 2-3; stamens 6-30. Female panicles shorter; calyx-segments 3-4. Ovary 2 celled; style short. Capsule 0.63 cm across, blackish, didynamous, clothed with minute waxy orbicular glands. Wood moderately hard, used as very good firewood.

c) **Botanical name:** *Dysoxylum binectariferum* Hook. f. et. Bedd.

   Vernacular name: Bandardima

   Family: Meliaceae

![Figure 3.3(c): *Dysoxylum binectariferum*](image)

A tree with 15 m in height and 1.2 m in girth; young shoots and inflorescence minutely pubescent. Bark grey outside, nearly smooth and warty on young stems, afterwards with light vertical fissures and horizontal wrinkles peeling off in thin papery flakes, pale yellowish brown inside, mottled with coarse strands of darker brown. Leaves alternate, estipulate; rachis 12.5-19 cm long, stout, angular, swollen at
base, pubescent; leaflets 6-8, alternate, 7.62-19.05 by 6.35-8.89 cm, obliquely ovate-oblong, short-usually abruptly acuminate, entire or with obscure distant teeth, thinly coriaceous, glabrous and dark-green above, pale underneath; petioles 0.50-0.76 cm long, channeled. Flowers pale-white, about 0.63 cm long, tetramerous. Calyx thick, cup-shaped, subentire, about half as long as petals. Petals velvety outside. Staminal tube mealy. Disk much exceeding the ovary, glabrous inside, 8-toothed; anthers 8. Ovary hairy. Capsule 5.08-6.35 cm long, globose with a narrowed base, smooth, at first pale-yellow, turning deep-orange, 4-celled, 4-seeds; seeds shining purple with a large yellow hilum; aril white; cotyledons green, plumule hairy. Wood moderately hard, fine grained, used for furniture, house constriction, firewood etc.

d) Botanical name: Bridelia retusa (Baill) Spreng.

Vernacular name: Kuhir

Family: Euphorbiaceae

Figure 3.3(d): Bridelia retusa

A middle to large deciduous tree. Bark darkish-grey, rough outside, exfoliating in irregular flakes, about 1.27 cm thick; inside light red, finally fibrous and soft with
faint streaks of lighter tissue. Leaves variable, 6.35-20.32 by 2.54-12.7 cm, elliptic, elliptic-lanceolate, ovate or obovate, acute or obtuse, entire or slightly crenulate rigidly coriaceous, dark-green and glabrous above, glaucous but pubescent on the nerves beneath. Flowers up to 0.50 cm across, greenish yellow. Male flowers: calyx segments triangular, acute; petals coarsely toothed or lobed. Female flowers: pedicels lengthening in fruit; calyx-segments triangular; outer disc annular; petals oblong or ovate, entire or undulate; styles 2, free, bifid from about half way. Wood hard, durable, used as firewood, for making house posts, agricultural implements etc.

e) Botanical name: *Myrsine semiserrata* Wall.

Vernacular name: Kalikath

Family: Myrsinaceae

![Image](image_url)

Figure 3.3(e): *Myrsine semiserrata*

A small tree or big shrub. Bark ashy grey outside, reddish-brown inside with somewhat regular narrow streaks of lighter tissue. Leaves 5.08-12.7 by 1.52-3.30 cm,
lanceolate-serrate or sparingly cuspidate-serrate towards the apex, coriaceous, glabrous; lateral nerves slender, 11-13 on either half; base cuneate; petiole 0.25-0.76 cm long. Flowers pinkish, usually 4-merous, 0.25 cm across, in dense axillary fascicles or below leaves; pedicels 0.50-2.03 cm long, glabrous. Calyx persistent. Anthers large, sessile, style short. Fruit 0.50-0.76 cm across, globose, filled with watery juice, bluish or pinkish purple when ripe on filiform pedicels. Wood moderately hard, used firewood and making charcoal.

f) **Botanical name:** *Celtis australis* Linn.

- Vernacular name: Nonibhola, Mohita
- Family: Ulmaceae

![Figure 3.3(f): Celtis australis](image)

Middle to large deciduous tree; branchlets drooping. Bark bluish or greenish grey, smooth, with small horizontal wrinkles; inside white, mottled with brown. Leaves alternate, 3.81-12.7 by 2.03-5.08 cm, ovate or ovate-lanceolate or ovate-
elliptic, acuminate, serrate or entire towards the base, coriaceous, dark green and glabrous above, often seabird, more or less pubescent beneath. Petiole 0.25-0.76 cm long; stipules about 0.76 cm long, subulate, caduceus. Sepals 4-5. Ovary sessile. Drupe ovoid or ellipsoid about 0.76 cm long, more or less rogués, woolly at the base; peduncles 1.27-5.08 cm long. Wood fairly hard, durable, used for firewood.

**g) Botanical name: Dysoxylum procerum** Hiern.

Vernacular name: Lali

Family: Meliaceae

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**Figure 3.3(g): Dysoxylum procerum**

A fairly large evergreen tree. Bark greenish-grey or grayish-brown. Leaflet 7-13, opposite or alternate, 15.24-30.48 by 6.35-11.43 cm, obovate or elliptic-oblong, slightly oblique at the base, thinly coriaceous, glabrous; petioles stout, 0.50-1.27 cm long. Panicles erect, stiff, 30.48-66.04 cm long with short horizontal puberulous branches; bracts subulate; pedicels very short, bracteolate; bud pubescent. Flowers 0.76-1.27 cm long, cream-white, fragrant Calyx pubescent; short. Petals 4, oblong,
valvate. Anthers 8, subsessile. Disk about one-third to two-thirds the length of the staminal tube, hairy at the mouth, encircling the hairy ovary; style slightly exceeding the staminal tube. Capsule up to 6.35 cm long, pyriform; seeds 2-3, black and shining with an orange aril. Heart wood reddish, fine grained, used for doors, windows, furniture, firewood etc.

h) Botanical name: *Terminalia myriocarpa* Heurck & Muell.

Vernacular name: Hollock, Jhaluka

Family: Combretaceae

![Figure 3.3(h): Terminalia myriocarpa](image)

A very large evergreen tree with pendulous branchlets; outer bark grey or brown, rough, peeling in vertical flakes; inside red, pale yellow towards the cambium, fibrous. Leaves 10.16-22.86 cm, oblong-lanceolate to elliptical oblong, acute or shortly acuminate, denticulate or entire; petiole thick, about 0.63-0.76 cm long with 1-2 elongated glands near the top. Flowers about 0.38 cm across, pink, each in the axils of small lanceolate or deltoid subulate bracteoles. Spikes slender, lax, arranged in ample
panicles, upper bracts spatulate, lower gradually larger and leafy. Limb of calyx tube expanded, glabrous or nearly so outside, pubescent within; teeth erect; disc with few or no hairs; ovary pubescent. Drupe about 0.38 cm long, yellow, 3 cornered, the lateral corners developing into short wings; 0.76-1.27 cm across the wings. Wood hard, durable, used as firewood, for making furniture, doors, windows etc.

i) **Botanical name:** *Syzygium cerasoides* (Roxb.) Chatt. & Kanjilal
   - Vernacular name: Kyamuna
   - Family: Myrtaceae

![](image)

**Figure 3.3(i): Syzygium cerasoides**

Small tree, bark is brown or reddish brown, twins quadrangular. Leaves broadly elliptic ovate or round, nearly oblong-oblanceolate or ovate, 12-15 by 7-15 cm, acuminate, secondary nerves irregular, 7-15; petiole 1-2.5 cm. Flowers white, sessile, in ternate trichotomous lateral panicles, mostly from old leaf scars. Calyx-tube 3.7-4.5 mm long and broad, lobes 4, sub-acute to obtuse, deciduous. Fruit globular to depressed globular, attaining about 10 by 10-12 mm, excavated at the apex, seed

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solitary, attaining about 8mm diameter, testa adhering somewhat to the pericarp and also to the glandular surface of the uniformly textured cotyledons. Radical basal or lateral. Wood reddish brown, hard, used as firewood, for making agricultural implements etc.

j) **Botanical name: Kydia calycina Roxb.**
   
   Vernacular name: Pichola
   
   Family: Malvaceae

![Figure 3.3(j): Kydia calycina](image)

A tall sized fast growing deciduous tree. Bark grey, exfoliating in long strips, reddish inside, green underneath the corky layer, innermost layers fibrous and lace-like. Leaves 7.62-16.51 cm long, suborbicula or orbicular, often broader than long, palmately 5-7 nerved and generally with as many lobes; base slightly cordate or truncate, glabrate above, downy pale beneath; petiole 2.54-10.66 cm long. Flowers generally white, 1.27-1.77 cm across, numerous, polygamaous, generally dioecious, in
much branched axillary and terminal panicles; pedicels slender, 1.27-1.77 cm long, generally tufted, stellate-downy; bracteoles 4-6, oblong or obovate, accrescent, persistent, downy at first, afterwards hispid with the bases of fallen hairs, prominently veined and spreading. Sepals ovate, acute, accrescent and incurved over the fruit. Petals clawed. Capsule depressed-globose, about 0.50 cm across, buff or yellow-villous. Wood white, soft, used in building construction, as firewood, for making charcoal etc.

**k) Botanical name:** *Mallotus phillipensis* (Lamk) Muell. & Arg.

Vernacular name: Senduri gooti, Kamala, Losan

Family: Euphorbiaceae

![Figure 3.3(k): Mallotus phillipensis](image)

A small to medium-sized evergreen tree up to 25 m tall and with a bole up to 50 cm in diameter. Bark thin, grayish-brown or darkish-grey. Leaves 7.62-17.78 by 3.81-6.35 cm, alternate, ovate, ovate-oblong or lanceolate, acuminate, entire or slightly dentate, glabrous above, pubescent beneath and with numerous close-set orbicular red
glands. Petiole 1.27-8.89 cm long, rusty-pubescent with a pair of glands at the junction with the blade. Inflorescence brown to red. Flowers small, dioecious. Male flowers clustered in erect terminal spikes which are often panicked, sessile or almost so. Female flowers usually solitary, sessile or nearly so in short spikes; sepals almost free, lobed when ripe, covered with a crimson powder, consisting of stellate hairs and grains of resinous substance. Seeds globose, black, 0.40-0.50 cm across. Wood moderately hard, used for rafters, tool handles, firewood etc.

1) **Botanical name:** *Albizia odoratissima* Benth.

   Vernacular name: Jati koro, Hiharu

   Family: Leguminosae

   ![Albizia odoratissima](image)

   **Figure 3.3(i): Albizia odoratissima**

   A large deciduous tree with spreading crown. Bark grey or brownish-grey to nearly black and rough outside, inside red with white streaks, soft, about 1.90 cm thick in old stems. Leaf-rachis 10.16-20.32 cm long. Pinnae 3-5 pairs, 7.62-16.51 cm long. Leaflets 7-20 pairs, 1.52-3.17 by 0.50-1.01 cm. Flowers sessile, fragrant. Calyx very small, campanulate, densely pubescent outside; teeth obsolete or minute. Corolla 0.38-
0.76 cm long, funnel shaped, hairy; lobes lanceolate, about 0.25 cm long. Stamens pale-yellow, about 2.03 cm long. Pod 12.7-30.48 by 1.77-3.04 cm, shortly stipitate, thin, flexible, tomentose when young, reddish brown or dusky greenish brown, broadly but rather indistinctly reticulate. Seeds 8-12. Wood hard, durable used for house building, agricultural implements, as firewood.

m) Botanical name: *Litsea polyantha* Juss.

Vernacular name: Sualu, Muga

Family: Lauraceae

![Figure 3.3(m): Litsea polyantha](image)

A middle sized deciduous tree with spreading crown. Bark grayish-brown, somewhat rough 1.77-2.03 cm thick. Leaves 7.62-20.32 by 3.30-10.16 cm, obovate-oblong, oblanceolate or elliptic-oblong, acute or rounded, coriaceous, dark green and glabrescent above, glaucous and rusty-pubescent beneath; petioles 1.27-2.54 cm long, pubescent. Flowers greenish yellow, about 0.50 cm across, in pedunculate umbelate heads; peduncles 0.50-1.27 cm long; pedicels villous, about 0.25 cm long; bracts 5,
nearly free. Stamens 9-13; filaments villous; glands stipitate. Fruit ovoid, 0.76-1.01 cm
long, blackish when ripe, supported by the persistent perianth and the thickened pedicels.
Wood used as cheap timber and as firewood.

n) Botanical name: *Mimusops elengi* Linn

Vernacular name: Bokul
Family: Sapotaceae

Figure 3.3(n): *Mimusops elengi*

An evergreen middle sized handsome tree often planted as avenue tree; young
parts rusty pubescent. Bark grey, fissured. Leaves 6.35-10.16 by 3.17-5.08 cm,
elliptical, acuminate, chartaceous, shining, glabrous; petiole 1.27-2.54 cm long.
Flowers 8-merous, about 7.62 cm across, creamy white, fragrant, star-like, solitary or
in fascicles. Calyx rarely in two rows (rarely 3+3). Corolla caducous, lobes usually 24
in two rows, all lanceolate and almost similar. Stamens 8; staminode rather petaloid,
membranous, fimbriate; anthers lanceolate, extrorse, apiculate. Overy hirsute, 6-8
celled; style subulate. Fruit rather variable, usually globose, ovoid or ellipsoidal, about
2.54 cm long, yellow orange. Seeds usually solitary, ovoid, compressed, slaty brown, shining. Wood light red colour, hard, durable, used for house posts, firewood etc.

**o) Botanical name: Bauhinia variegata Linn.**

Vernacular name: Bogakatra, Kurol, kotora, Kanchon

Family: Leguminosae

![Figure 3.3(o): Bauhinia variegata](image)

A moderate sized tree with dark grey or brown somewhat rough bark. Leaves 6.60-15.24 cm long, as broad as long or sometimes broader, usually deeply cordate, 11-15, nerved, thinly coriaceous, grey glaucous and puberulous along the nerves beneath; petiole 2.54-3.81 cm long. Flowers are large, pure white, 5.08-7.62 cm across when fully opened. Calyx covered with grey and somewhat sticky pubescent tube, 1.27-2.54 cm long, slender; limb spathaceous, 5 toothed at the apex, 1.52-3.04 cm. Petals 3.81-5.08 cm long, obovate or obovate-oblong. Stamens usually 5, rarely fewer; filament stout, unequal, incurved. Ovary with a long stipe which is extruded 1.27-1.77 cm beyond and adnate at the bottom to the calyx tube, covered with mealy pubescence.
and with spreading hairs along the sutures; style short. Pod 15.24-25.40 by 1.77-2.28 cm, hard flat, glabrous, prominently veined when dry, slightly falcate and dehiscent. Seeds 10-15. Wood moderately hard, used as cheap timber, as firewood etc.

**p) Botanical name:** *Premna integrifolia* Linn.

Vernacular name: Genderi

Family name: Verbenaceae

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**Figure 3.3(p):** *Premna integrifolia*

A small tree or large shrub; trunk and larger branches are thorny. Bark yellowish green, lenticellate, white inside. Leaves 5.08-10.16 by 2.54-6.35 cm, oblong-ovate or broadly elliptic or oblong-ovate, entire, undulate, sometimes coarsely dentate towards the apex, sub-obtuse or very shortly acudentate, glabrous on maturity; lateral nerves 4-5 on either half; base rounded or sub-acute; petiole 1.01-1.77 cm long. Flowers are small, greenish yellow. Calyx 2-lipped; one lip 2-toothed; the other sub-
entire. Corolla sub equally 4-lobed. Drupe 0.50 cm across, globose, endocarp, obscurely veryucose. Wood light-creamy brown, moderately hard.

q) Botanical name: *Talauma hodgsonii* Hk. f. &Th.

Vernacular name: Boramthuri, Dat-bhola

Family: Magnoliaceae

![Figure 3.3(q): Talauma hodgsonii](image)

A small tree with a few spreading branches. Bark greenish grey, warty. Otherwise smooth, with distant horizontal wrinkles, often with large white patches; inside brownish-yellow, fibrous, 0.50-0.76 cm thick. Leaves 20.32-50.80 by 10.16-20.32 cm, oblanceolate, rounded or suddenly apiculate, thinly coriaceous, quite glabrous, red and erect when young. Petiole 2.54-6.35 cm long, terete, with a faint scar of fallen stipules, much swollen at the base. Flowers large, terminal. Sepals, greenish-purple. Petals greenish-white at the base, bright-red above. Fruit ovoid, 10.16-15.24 by 6.35-8.89 cm. Carpels beaked, woody, dehiscent by the vertical suture, separating from

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the axis leaving the red seeds attached to it at the upper end of the empty pits by an elastic cord. Wood grey, hard, even-grained, used for house constriction, firewood etc.

r) Botanical name: *Pterospermum acerifolium* Willd.

Vernacular name: Hatipaila, larubondha,

Family: Sterculiaceae

![Figure 3.3(r): *Pterospermum acerifolium*](image)

An evergreen tree up to 25 m in height and 2.5 m in girth. Bark dark-brown and rather rough outside, inside deep purplish red. Leaves 20.32-38.10 by 15.24-30.48 cm; very variable in size and shape even in the same twig, somewhat obliquely obovate or orbicular, glabrous and deep green above, grayer brownish tomentose beneath; petiole 10.16-30.48 cm long, striate; stipules multifid, caducous. Flowers solitary or 2-3flowered cymes, 12.70-15.24 cm across, fragrant; peduncles about 1.27 cm long; bracteoles multifid, deciduous. Calyx-segments 10.16-12.70 by 0.76-1.27 cm, linear, very fleshy. Filaments 15, 2.54-3.81 cm long, filiform, glabrous, in threes against each calyx-segment, with a staminode 5.08-7.62 cm long between, all forming
a tube about 2.54 cm long below the ovary and adnate to the gynophores. Ovary oblong, obscurely 5-angled, brown-shaggy. Wood strong, durable, reddish brown, used for firewood.

s) Botanical name: *Vitex altissima* Linn.

Local name: Ahoi

Family: Verbenaceae

![Figure 3.3(s): Vitex altissima](image)

A middle sized tall deciduous tree up to 30 m in height. Bark grayish, about 2.54 cm thick. Leaves 3-foliolate; petioles winged up to 10.16 cm long. Leaflets 6.35-20.32 by 2.03-4.57 cm; lateral leaflet lanceolate or ob lanceolate, long acuminate, entire; lateral nerves numerous with finely reticulate venation; base acute or cuneate; petiole 0-0.25 cm long. Flowers white tinged with blue or violet, in panicles with spiciform interrupted branches of small grey pubescent cymes; bracts small, caduceus. Calyx about 0.30 cm long; teeth short, triangular. Corolla about 0.50 cm long, woolly.
Ovary fulvous-villous. Drupe about 0.63 cm across, irregularly globose, purplish, often dotted with white specks supported by the accrescent calyx. Wood hard, yellowish-brown, used for timber, firewood etc.

**t) Botanical name: Schima wallichii Choisy.**

Local name: Makori sal, Noga-bhe

Family: Ternstroemiaceae

A large tree up to 28 m. in height and 3.5 in girth with a narrow crown in youth but develop to a very large spread one after height is completed. Bark surface ruggedly cracked into small, thick, angular pieces, red-brown to dark grey; inner bark with skin-irritating fibers, bright red in colour, 1.77-3.81 cm thick. Branchlets lenticellate, buds and young parts adpressed pubescent villous. Leaves 8.89-24.13 by 3.55-8.12 cm, oblong or elliptic-lanceolate, acute or acuminate, usually entire, thinly coriaceous; glabrous and shining above. Petioles 1.52-2.03 cm long, sharply margined, more or less pubescent. Flowers white, scented, axillary, solitary, 3.04-5.08 cm...
diameter. Sepals 5, imbricate. Petals 5, connate and silky pubescent outside towards the base. Stamens many; ovary hairy towards the bottom, upper portion glabrous. Fruit a woody subglobose capsule, 1.27-1.77 cm diameter, silky, opens by 5 valves. Seeds 2-6 in each cell. Wood moderately hard, durable, good for firewood and making charcoal.

u) **Botanical name:** *Alnus nepalensis* D. Don.

Vernacular name: Uttis

Family: Betulaceae

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![Figure 3.3(u): *Alnus nepalensis*](image)

A large deciduous tree height up to 25-30 m; bark compact, silvery-grey; branchlets glabrous; young shoots usually pubescent. Leaves alternate, 6.35-17.78 by 3.81-8.89 cm, elliptic or elliptic- lanceolate, acute, entire or somewhat denticulate, coriaceous, glabrous above, slightly pubescent along the nerves beneath when young, usually glaucous and dotted with resinous minute dots; lateral nerves 10-18 on either half; base narrowed or rounded; petiole 0.76-2.03 cm long. Male catkins 10.16-
25.4 cm long, terminal, drooping, panicked; flowers supported by bracts and bracteoles; bracts 3-flowered with usually 4 bracteoles adnate each bract; sepals 4; stamens 4; Female spikes 0.50-0.76 cm long, erect. Wood light, used as firewood.

v) Botanical name: *Quercus lanata* Sm.

Vernacular name: Safed banjh

Family: Fagaceae

![Figure 3.3(v): Quercus lanata](image)

Trees to 30 m tall, evergreen. Bark thick, brown-ash grey, lenticellate, peeling into thin plates; inside slightly fibrous, deep pinkish 1 cm thick. Young branchlets densely grayish brown pubescent, glabrescent. Petiole 0.5-1.5 cm, grayish brown tomentose, glabrescent; leaf blade narrowly ovate-lanceolate to narrowly elliptic, 9-20 × 3-8.5 cm, densely with grayish stellate hairs but glabrescent, adaxially densely pubescent especially on midvein, base rounded to broadly cuneate, margin sharply serrate, apex acuminate; secondary veins 12-17 on each side of midvein; tertiary veins abaxially conspicuous. Cupule cupular, 0.6-1 × 0.8-1.5 cm, enclosing 1/4-1/2 of nut, wall ca. 1 mm thick. Nut ovoid-conical, 1.5-2 × 1-1.2 cm, glabrous; scar ca. 4 mm in
diam., slightly raised; stylodium ca. 1 mm. Wood hard, red-brown in colour, used for firewood and making charcoal.

w) Botanical name: *Quercus leucotrichophora* A. Camus

Vernacular name: Lal banjh

Family: Fagaceae

![Figure 3.3(w): *Quercus leucotrichophora*](image)

An evergreen tree with height up to 30 m. Bark smooth, tan-brown, lightly furrowed and corky with age. Leaves oblong or ovate - lanceolate, stiff leathery, white or grey tomentum beneath; sharply toothed, 6-16 cm long, dense white-woolly hairs on the underside; lateral nerves 13-16 on either half; base acute, obtuse or rounded; petiole 1-1.5 cm long. Male spikes dense hairy and clustered, female flowers usually sessile. Flowers arise in catkins. Male catkins are woolly-haired. Fruits acorn 1.1-1.8 cm. long, 0.9-1.2 cm. wide; ovoid, mucronate, glabrous; singly or paired; enclosed 1/3 to 1/2 cup; cup sessile, 1 cm in diameter. Wood hard, red-brown in colour, used for firewood and making charcoal.
x) Botanical name: *Rhododendron arboreum* Sm.

Vernacular name: Gurans.

Family: Ericaceae

![Rhododendron arboreum](image)

**Figure 3.3(x): Rhododendron arboreum**

A medium sized or small evergreen tree. Bark reddish brown, corky, peeling off in small flaks; blaze reddish brown or pinkish with white lines; branchlets glabrate. Leaves crowded at the ends of branches 9.14 by 1.90-4.44 cm, narrow elliptic or oblong-lanceolate, acute, margins recurved. Petiole 0.76-1.77 cm long. Flowers red. Pedicels 0.50-1.01 cm long. Calyx subrotate: lobes unequal, about 2.54 cm long, acute. Corolla campanulate, 3.04-3.81 cm long, slightly zygomorphic. Stamens 10. Overy white or grey, woolly, 0.38 cm long, with a purple line at the base, usually 10 ribbed, 10 celled, with a false dissepiment between each, about 3.81 cm long, tinged with red; stigma dilated. Capsule 2.54 cm long, cylindrical, longitudinally ribbed and curved, mealy. Seeds ellipsoid, minute. Wood soft, used for making charcoal, furniture, as fuelwood, etc.
y) Botanical name: *Myrica esculenta* Buch.-Ham. ex D. Don.

Vernacular name: Kaphal

Family: Myricaceae

![Figure 3.3(y): Myrica esculenta](image)

A small or moderate sized evergreen tree. Bark grayish-brown, rough, vertically wrinkled, finely fibrous, 0.76 cm thick; extremities pubescent. Leaves 5.08-15.24 by 1.27-3.81 cm, lanceolate, oblanceolate or obovate, nearly entire or sharply spinous-serrate, obtuse or acute, coriaceous, glabrous above, with resinous dots beneath; lateral nerves 12-20 on either half, anastomosing at the ends to form a marginal vein; base acute; petiole 0.50-1.52 cm long. Male spikes sometimes with female flowers at the top. Fruit about 2.54 cm long ellipsoid or ovoid, tubercled, reddish or cheese colored when ripe. Wood moderately hard, used for furniture, house construction, Fuelwood etc.
2) Botanical name: *Ehretia acuminata* R.Br.

Vernacular name: *Gual*

Family: Boraginaceae

![Figure 3.3(z): Ehretia acuminata](image)

A large tree; stems more or less fluted. Bark grey with vertical fissures, 1.27 cm apart, 0.76 cm thick, composed of many fibrous ribbons; blaze whitish, rapidly turning dirty brown. Leaves 5.08-15.24 by 2.54-6.35 cm, elliptic, elliptic-oblong, acuminate, acute, and sharply serrate, chartaceous, glabrescent, shining above; lateral nerves 8-10 on either half; petiole 1.27-3.81 cm long. Flowers white with an unpleasant smell. Calyx small, ciliate. Corolla tube short; lobes 0.30 cm, reflexed; style bifid for less than half its strength. Drupe 3.04-0.40 cm in diameter, ellipsoid with two 2-celled Pyrenees, 4-seeded. Wood light brown, moderately hard, used for house building and firewood.
3.4 Field sampling

26 different tree species of the age groups of 5 to 10 years old were selected for the study. Three randomly selected trees of each of the species were sampled from a particular locality. For each species, 20 cm long sample (branch stem) having 7-10 cm diameter was cut outside the bark. Each sample was labeled and bagged immediately in a polyethylene bag and sealed to avoid loss of moisture from the freshly cut trees. The sealed samples were brought to the laboratory within 12 h following collection. Samples of each of the tree species collected from different localities were thoroughly mixed to make a representative sample. The sampling localities for each of the tree species are presented in Annexure-II. The collected tree species were also sampled to study the drying profile of the species.

3.5 Drying profile

Drying profiles to observe the drying rates of the tree species were prepared. All the freshly cut stem samples were weighed accurately within 12 h of cutting. They were then left to dry in the sun for 8 weeks. A drying profile of each of the samples was maintained by recording the weight loss of the samples at one-week interval.

3.6 Pair-wise comparison (PWC) ranking of fuelwood

Key informants were used to identify fuelwood qualities according to Kumar [8]. 20 key informants with equal number of men and women were selected from each locality considering their experience with firewood utilization as source of energy. Pair-wise ranking was done to identify the firewood property and ranked species accordingly [9]. Finally, a ranking matrix for 26 species using indigenously preferred ten quality criteria was drawn and scores were assigned to the species according to their comparative ranking value.
3.7 Analytical test on firewood properties.

3.7.1 Sample preparation

A disc of 2 cm thickness and 4 cm diameter was taken from each of the freshly cut tree species without removing the bark portion and kept in an oven for moisture removal. The oven-dried disc taken from each of tree species was then ground (using a Wiley mill) to pass a 0.4 mm (40 mesh) screen (as per TAPPI T257 Om-85 methods). The ground sample of individual tree species was kept in air-tight containers for further analysis.

3.7.2 Preparation of extractive free samples

Wood extractives are materials soluble in neutral solvents and are not generally considered as part of the wood substances. These materials should be removed before any chemical analysis of wood substances.

Ethanol-benzene mixture was used to extract waxes, fats, some resins, and possibly some portions of wood gums. Hot water was used to extract tannins, gums, sugars, starches and colouring matter. The procedures for ethanol-benzene and hot water soluble extractives are described below:

3.7.2.1 Determination of total extractives content

Total extractives content was determined according to the method reported by Senelwa et al. [10]. The extractives content are distinguished into two categories — organic (non-polar) solvents soluble extractives (i.e. ethanol: benzene mixture and ethanol, OEC), and water (polar solvent) soluble extractives. The sum of polar and non-polar solvent soluble extractives content was taken together as total extractives content (TEC).

Approximately 2 g of oven dry ground sample of particle size 180-250 μ was weighed and taken into a filtering thimble having coarse porosity. The tip of the
thimble was closed with loose cotton to prevent expulsion of the sample. The thimble was then placed into a soxhlet apparatus attached to a 250 ml extraction flask fitted with a condenser. To determine OEC, the samples were extracted with 125 ml (95% ethanol and benzene in ratio 33: 67) for 4 h followed by another 4 h extraction with 125 ml of 95% ethanol. The ethanol was drained off and evaporated to constant weight. The samples were further boiled in distilled water at 100 °C (boiling water bath) for 3 h and then oven dried at 80 °C to constant weight. OEC and TEC were determined as % weight loses after extraction with organic solvent (ethanol and benzene mixture) followed by hot water extraction.

3.7.3. Proximate analysis

Proximate analysis gives the relative amount of ash, fixed carbon and volatile matter in a fuel as a percentage of its oven-dry weight. The detail procedure is given below:

3.7.3.1 Determination of Moisture Content

The moisture content was determined according to the method described in the Forestry Hand Book [11] and ASTM D4442-07. Approximate 10 g of sample was weighed immediately upon sampling and then air-dried. This air-dried sample was taken immediately in an aluminum moisture box and kept in an oven heated at 105 ± 3°C until constant weight was obtained. The difference of the oven dry weight of the sample and the fresh weight of the sample was used to determine the percentage of moisture content as follows:

\[
Moisture\ content\ (%) = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Fresh weight}} \times 100
\]

For each sample, the estimation was done in triplicate and the mean value was reported.
3.7.3.2 Determination of Ash content:

For determination of ash content, TAPPI standard method, T211 om-85, was followed [12]. At first, an empty 25 ml. silica crucible was heated in a muffle furnace at 575 ± 25°C for 15 min. and allowed to cool in a desiccator for 45 min. and then weighed accurately. Representative sample of each of the plant parts was made oven-dry, weighed and transferred into the crucible and kept in a muffle furnace at 575 ± 25°C to ignite for a period of 3h or longer to burn away the carbon, completion of which was indicated by the absence of black particles. Crucible was then removed from the furnace and kept in a desiccator and weighed accurately. The percentage of ash content was calculated as follows:

\[
\text{Ash content (\%)} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100
\]

For each sample, the estimation was done in triplicate and the mean value was reported.

3.7.3.3 Determination of Volatile matter

Volatile matter of wood samples was determined by the method described in ASTM Test No. D-271-48. A platinum crucible of 10 ml capacity was taken and its surface was cleaned by rubbing with fine steel wool. The crucible was heated in a furnace at 950°C for 2 min and then cooled in a desiccator for 15 min. The weight of the platinum crucible was measured. The crucible was filled up to 1/2 to 3/8 inch with the ground oven dried samples and the gross weight was recorded. Following this the crucible was heated in a muffle furnace at 950 °C for 2 min. The crucible was removed from the furnace and cooled in air for 5 min and then cooled in a desiccator for 15 min. For each sample, the estimation was done in triplicate and the mean value is reported. The percentage of weight loss of the samples was reported as volatile matter and calculated as follows:
\[ \text{Volatile matter} (\%) = \frac{\text{Weight loss of dry sample}}{\text{Net weight of dry sample}} \times 100 \]

3.7.3.4 Determination of Fixed carbon content

Fixed carbon content of wood and wood base materials (bark) was determined by simple calculation as given in ASTM Test No. D-271-48. The calculation was done as follows:

\[ \% \text{ F.C. (on dry basis)} = 100 - [\text{volatile matter} (\%) + \text{ash} (\%)] \]

3.7.4 Ultimate analysis of the samples

Carbon, hydrogen and nitrogen contents of the wood and bark samples were determined by using an elemental analyzer (PE 2400 C, H, N - analyzer, Perkin Elmer). Chlorine and sulphur were not considered since they are known to be negligible for wood and wood base materials. Oxygen was determined by difference between the total weight of the sample and the combined weight of C, H, N and ash content in it [13].

3.7.5 Determination of Specific gravity

Specific gravity of the samples was determined as per ASTM – D 2395-93 (volume by water/ mercury immersion method).

Procedure:
Weight: The weight of the specimen was measured to a precision of ± 0.2%. Before weighting the specimen it was dried in an oven maintained at 103 ± 20 °C.

Volume: The volume of oven-dried specimen was determined by measuring the volume of water displaced by it.
Mode of measurement:

A container was placed holding enough water to completely submerge the specimen on the pan of an automatic balance. The specimen was held by means of a sharp, pointed, slender rod so that the specimen was completely submerged without touching the sides of the container. The weight added to the automatic balance was equal to the weight of water displaced by the specimen. The weight in grams was numerically equal to the volume in cubic centimeters.

Calculation

Specific Gravity: Specific gravity was calculated as follows:

\[ \text{Sp. gr.} = \frac{KW}{V} \]

Where

\[ W = \text{weight of specimen at derived moisture content} \]
\[ V = \text{Volume of specimen at desired moisture content and} \]
\[ K = \text{Constant whose value was determined by the units used to measure weight and volume as follows:} \]
\[ K = 1, \text{ when weight was in g and volume was in cm}^3. \]

For each sample, the estimation was done in triplicate and the mean value was reported.

3.7.6 Determination of Biochemical constituents of the samples

Cellulose, hemicelluloses and lignin were determined by using the Fibertec I and M Systems (Foss AB, Denmark) as described by Van Soest [14]. This method is based on subsequent steps of chemical treatments to solubilise “non-fibre” components and final determination of the residue obtained. Before the determination of biochemical constituents, ground samples were extracted with acetone (100%) at 5°C and water at 60–70°C. Extractions were repeated several times. The residues were
dried and used for the determination of acid detergent fibre (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL).

NDF was determined after treatment with a neutral detergent solution (sodium lauryl sulphate and EDTA), and the residue consisted of cellulose, hemicelluloses and lignin. ADF was determined after treatment of the residue with an acid detergent solution (cetyltrimethylammonium bromide in sulphuric acid solution). The residue consisted of cellulose and lignin. Finally, ADL was determined after initial treatment for ADF measurement followed by removal of the cellulose fraction through extraction using 72% H$_2$SO$_4$. This residue contains only lignin. A fraction of acid-soluble lignin and cellulose could be lost during the procedure. Acid-resistant residue was recovered by filtration on a glass crucible with an asbestos filter, carefully washed and dried at 70°C for 24h to constant weight. This acid insoluble residue is insoluble lignin (hereafter called ‘lignin’). After weighing, the residue was ashed at 525±25°C for at least 5 h and lignin was calculated after correcting for mineral elements.

Simple subtraction rules were used to calculate cellulose and hemicelluloses: ADF – ADL = cellulose and NDF – ADF = hemicelluloses. The results for lignin, cellulose and hemicelluloses were expressed as percentage of dry mass of wood species (% dw). For each sample, the estimation was done in triplicate and the mean value was reported.

3.7.7 Determination of Gross calorific value (GCV)

Gross Calorific value (GCV) was determined by using an auto bomb calorimeter (Changsha Kaiyuan Instruments Co, 5E-1AC/ML). About 1 g of oven dried sample tablet was completely combusted in an adiabatic bomb at 3.4 MPa Oxygen pressure. The instrument displayed the GCV of each samples after each run. The mean value of the triplicate samples was reported.
3.7.8 Determination of Gross Calorific Value (GCV), Net Calorific Value (NCV) and Usable Heat Content (UHC) at green moisture:

GCV, NCV and UHC of wood species at their green moisture were calculated by the method reported by Lyons et al. [15] as follows

GCV (at green moisture) = C_{gd} \times (1-m) \text{ MJ/kg}

NCV (at green moisture) = 17.28 - 19.72 \text{ m MJ/kg}

UHC (at green moisture) = 14.64 - 17.43 \text{ m MJ/kg}

Where \( C_{gd} = \text{GCV (oven dry weight)} \), \( m = \text{moisture content, as a fraction of wet weight} \).

3.7.9 Ash analysis for elemental determination

The analysis of ash for determination of elements like Ca, Mg, Na, K, P, Si, Mn, Cu, Zn, Cd, Pb etc. was done by using an Atomic Absorption Spectrophotometer (Thermo Scientific, iCE 3000 C113500100v1.30). For this, 500 ± 5.0 mg ground extractive free samples were digested in a muffle furnace at 500°C for 4 hrs. Ash samples were digested by using Nitric-Perchloric acid as per the procedure recommended by the AOAC [16]. For this, 1 gm. of ash sample was transferred in a 250 ml digestion tube and 10 ml HNO₃ was added to it. The mixture was boiled for 30-40 min and then cooled. Again, 5 ml 70% perchloric acid was added to it and boiled gently until dense white fumes appeared. The mixture was then cooled and 20 ml distilled water was added to it. The mixture was re-boiled and cooled to ambient temperature. Finally, the mixture was filtered through Whitman no. 42 filter paper and the filtrate obtained was transferred to a volumetric flask. The final volume was then adjusted to 25 ml by addition of distilled water.
3.7.10 Fuel value index calculation

The fuel value index (FVI-I) was calculated by the method reported by Purohit and Nautiyal [17] as follows:

\[
FVI = \frac{\text{Calorific value (kcal/g)} \times \text{Density (g/cm}^3\text{)}}{\text{Ash content (g/g)} \times \text{Moisture content (g/g)}}
\]  

(1)

Fuel Value Index (FVI-II) of the fuelwood species was calculated by using the modified method reported by Bhatt and Todaria [18], where

\[
FVI = \frac{\text{Calorific value (kcal/g)} \times \text{Density (g/cm}^3\text{)}}{\text{Ash content (g/g)}}
\]  

(II)

Fuel Value Index (FVI-III) of the fuelwood species was calculated by Deka et al. [19] is as shown below:

\[
FVI = \frac{\text{Calorific value (kcal/g)} \times \text{Density (g/cm}^3\text{)}}{\text{Moisture content (g/g)}}
\]  

(III)

3.7.11 Thermogravimetric analysis

The fuelwood samples were subjected to thermogravimetric analysis in an air atmosphere at heating rate of 10 °C/min. 10 mg sample for each species was heated at the preselected heating rate from ambient temperature to 1000 °C in a Pyris diamond TG/DTA analyzer (PERKIN ELMER). In the experiment air was fed at a constant flow rate of 100ml min^{-1}. The continuous on-line records of weight loss and temperature were obtained to plot the TG curves and the derivative thermogravimetric (DTG) curves.
3.7.11.1 Combustion characteristics

The important combustion characteristics such as Peak temperature, Burnout temperature \( T_{BO} \), Maximum combustion rate \( \text{dw/dt}_{\text{max}} \) and Mean combustion rate \( \text{dw/dt}_{\text{mean}} \) were determined from TGA data and TG/DTG curves. Mean Combustion rate is the mean value of Combustion rate in the temperature range (i.e. from the temperature at which degradation start and at which it finish). Burnout temperature \( T_{BO} \) is the temperature at the end of combustion where combustion rate is less than 1%. Ignition temperature \( T_i \) was determined from TG/DTG curves according to Wang et al. [20] and is shown in Figure 3.4. To determine the ignition temperature, two points on the TG curve should first be identified. One (marked as P) is the point at which a vertical line from the sharp DTG peak (highest dw/dt value) crosses the TG curve. The other (marked as S) is the point at which volatilization begins. A tangent to the TG curve at P and another horizontal tangent to S are drawn. The point at which these lines cross is marked as IG, which corresponds to the ignition temperature.

![Figure 3.4: Determination of ignition temperature](image)

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3.7.11.2 Combustion Characteristic Factor (CCF)

Combustion Characteristic Factor (CCF) of the fuelwood species were calculated according to the method reported by Wang et al. [20] and Jiricek et al. [21] as shown below:

\[
\text{Combustion characteristic factor } (S) = \frac{\left(\frac{dw}{dt}\right)_{\text{max}} \times \left(\frac{dw}{dt}\right)_{\text{mean}}}{T_i^2 \times T_{BO}}
\]

Where

\(\left(\frac{dw}{dt}\right)_{\text{max}}\) = Maximum combustion rate

\(\left(\frac{dw}{dt}\right)_{\text{mean}}\) = Mean combustion rate

\(T_i\) = Ignition temperature

\(T_{BO}\) = Burnout temperature

3.7.12 Statistical analysis

The statistical analysis has been carried out using SPSS software.

3.7.13 Overall ranking (OR)

An overall ranking of studied fuelwood species was obtained on the basis of PWC, FVI and CCF ranking.
References:


12. TAPPI Test methods. Atlanta (USA), Technical Association for Paper & Pulp Industries (TAPPI) publication.

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