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TREE ALLOMETRIC EQUATIONS IN SOUTH ASIA

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ABSTRACT

Estimation of volume, biomass and carbon stocks support several applications from the commercial exploitation of timber to global carbon cycle. Especially in the latter context the estimation of tree biomass with sufficient accuracy is essential to determine annual changes of carbon stored in particular ecosystems. Under the aegis of UN - REDD programme an extensive database on tree allometry in South Asia (Bangladesh, Bhutan, India, Nepal, Maldives, Pakistan and Sri Lanka) was prepared by extensive and exhaustive literature collected from the region by institutional visits, bibliographic databases and FAO reports. An evaluation of this data on tree allometry in South Asia shows that there exists a total of 4456 equations on volume, biomass, BEF, carbon and other growth variables for 375 species belonging to 96 families and 275 genera. Proportionate allocation of allometric models for different species in the collected documents is not homogenous with commercially important ones capturing more percentage share of equations. Vague description of tree components and output terms reduces the quality of allometric equations developed in the region. Also the geographical distribution of these allometric equations is highly skewed and conscious efforts should be taken to unearth documents on allometry in the neglected life zones.

Key words : Tree allometric equation, Estimation of volume, Biomass, Carbon stock, South Asia.

Introduction

Estimation of volume, biomass and carbon stocks support several applications from the commercial exploitation of timber to global carbon cycle. Especially in the latter context the estimation of tree biomass with sufficient accuracy is essential to determine annual changes of carbon stored in particular ecosystems. Such estimations are the core of carbon sequestration projects (sink projects) that deals with the accumulation and long-term storage of atmospheric carbon in vegetation and soil organic matter. These projects give a better understanding of nature's carbon sinks, and the valuable information and evidence generated therein will help addressing the physical, natural, social and economic aspects of climate change in a more factual way.

Forest ecosystems act as both source and sink of carbon and thus play a crucial role in global carbon cycles. Forests form an important aspect of active carbon pool as they account for 60 per cent of terrestrial carbon storage (Wilson and Daff, 2003). Tropical forests, which constitute 60 per cent of world forests and 43 per cent of terrestrial net primary productivity (Dixon *et al*., 1994), dominate the role of forests in the global carbon flux and stocks, and hence demands great attention with respect to carbon policies and estimations. In spite of their importance to the carbon cycle, there is little information on the carbon budgets of tropical forest systems in South Asia. Efficient and accurate national systems for Measurement, Reporting and Verification (MRV) systems are required in the region to properly assess carbon stocks and support international climate change efforts. The use of suitable allometric equations is a crucial step in such endeavours, making precise and non destructive estimation of above and belowground biomass and carbon storage in the region.

Allometry, generally relates some non-easy to measure tree characteristics from easily collected data such as dbh (diameter at breast height), total height, or tree age and provides relatively accurate estimates. Models for volume, biomass or nutrient content within the trees belong to the same class as methodologies for sampling trees and fitting and using the equations are similar. Despite their apparent simplicity, these models have to be built carefully, using the latest regression techniques. Tree growth parameters varies considerably with species, site quality, location, climatic regimes, altitude etc. and therefore becomes necessary to obtain accurate and precise tree allometric estimates in order to

This article analyses a total of 4456 published tree allometric equations on volume, biomass, carbon and other growth variables in South Asia. Importantly, it highlights the existing lacunae in tree allometry in the region and will help policy makers and researchers in development and implementation of policies and programmes such as REDD+.

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improve understanding of the role of these carbon sinks in global carbon cycle. An unsuitable application of allometric equation may lead to considerable bias in carbon stocks estimations (Henry *et al.,* 2013).

In the recent past carbon sequestration has received particular attention in South Asia due to global initiatives on climate change and realization of potentials of tropical forests to attract financial resources under Clean Development Mechanisms (CDM) of Kyoto Protocol. Though the market for CDM sinks were limited in the first commitment period of Kyoto, 2008 -12, a huge potential is envisaged for afforestation and reforestation activities in developing countries beyond 2012 (De *et al*., 2005). South Asia with a sizable proportion of tropical forests can harness a good proportion of these global initiatives. However, the pre requisite to actual commercialization of these carbon sinks depends very much on efficient and accurate methods of estimating biomass stocks and carbon sequestration rates. Though large numbers of tree allometric models have been developed for volume, biomass and carbon stocks estimations in South Asia, their accessibility is very limited as they are mainly confined to scientific articles, reports from private companies and hard copies in institutional or national libraries. The development of new allometric equations is time consuming, laborious and involves destructive harvesting of trees. In order to provide accessibility and facilitate identification of gaps of existing tree allometric models to the national institutions and other stakeholders, it is important to inventory all existing volume and biomass allometric equations. The objective of this study is to provide a regional overview on the status of tree allometric equation in South Asia (Bangladesh, Bhutan, India, Nepal, Maldives, Pakistan and Sri Lanka) to support national forest monitoring system and improve assessment of the necessary parameters to support policies and measures. As we couldn't find any allometric equations from Maldives, it is not included in further descriptions.

Data compilation

Review of available literature

The database on existing tree volume, biomass and allometric equations was developed by collecting data from several secondary sources. The first stage of the database development was extensive literature survey and identification of key stakeholders who could make significant contributions to the database. An online search with the selected keywords helped to identify individual researchers and Institutes in the region with good experience in tree allometry. Visits to research and educational Institutions in the region yielded hard copies of dissertation thesis and old research papers which contained large volumes of recent works on allometry in the region. Publications/ documents of the Food and Agriculture Organization (FAO) also served as good source for many allometric equations in the database. Further soft copies of tree, stand and sprout allometry of South Asia published in peer reviewed journals were collected from bibliographic databases such as Science Direct – biological Sciences, Springer Link, CABI, AGRIS, AGRICOLA, JSTOR and Indian Forestry Abstracts (http://www. indianforestry.org). In spite of our earnest attempts the database is not exhaustive and may have several omissions of published literature in the region. However, it is a first such attempt to create a regional database for South Asia that can be progressively completed.

Data organization

The extensive literature survey produced thousands of documents, which were filtered to give 550 documents containing relevant information. These documents were deciphered and entered into Excel datasheets. The database is available online at *www.globallometree.org* , an international web platform developed by FAO, UNITUS and CIRAD along with various regional organizations to support volume, biomass and carbon stock assessments. The database provides information on the type of population, ecosystem, bioclimatic zones, equation parameters, fit statistics and geographic location where the equations were developed or applied. Detailed information on the database structure and methodology for entering the data in the database was provided by Baldasso *et al.*, 2012, a tutorial developed for this purpose.

The equations covered in the database were found to contain many vaguely defined vegetative components (big and small roots, trunk, small and large branches, above ground biomass etc.). For standardizing the data and its easy usage, the vegetative components were divided into 11 different compartments and defined (Fig. 1). The equations in the original sources were thoroughly checked and carefully converted to our newly defined system.

Taxonomical hierarchy of the plant/ tree for which the equations were developed was explained upto family level (species, genus and family) in three different fields. It should be noted that no attempts were made to update the nomenclature to the present status, but we have used the species and common names as given in the original source .

Data description and structure

The database consists of 74 variables grouped into 7 different categories

1. Plant ecology (Population and Ecosystem)
2. Geographical location where the equation was developed or applied (Continent, Country, Biomes)
3. Equation parameters (variable characters and ranges)
4. Tree vegetation components (Bark, Root, Stump etc.)
5. Taxonomical description (Family – Genus- Species)
6. Statistical Information (R^2, adjusted R^2, bias correction, RMSE and standard error of mean)
7. Bibliography

Component wise analysis of allometric equations in South Asia

Document status

Of the thousands of materials collected from the region, 550 documents were found to be in line with the objectives of the project. Further refinement yielded 466 reports/articles/other documents which were considered in the present database. 15% of the documents (i.e., 84 nos.) either didn't contain any equations or couldn't technically fit into the defined parameters of the database and hence not included (Table 1). 67.81% of the total articles covered in the database were collected from India. India's vast geographical extend along with its large network of research institutes has enabled generation of large volumes of tree allometric equations compared to other nations included in the study.

Table 1: Country wise literature coverage in South Asia

Country	Total documents collected	Documents covered in the database	Documents not covered for technical reasons
Bangladesh	80	72	8
Bhutan	13	10	3
India	371	316	55
Nepal	40	32	8
Maldives	--	--	--
Pakistan	13	12	1
Sri Lanka	29	24	5
Others	4	0	4
Total	550	466	84

The proportion of equations contributed to the database by individual nations in South Asia varied as India > Bangladesh> Nepal > Sri Lanka> Pakistan> Bhutan. We couldn't find any tree allometric equation reports from Maldives. It should be noted that the database is a compilation of available literature and the proportional contributions may not have a bearing on the actual volume of work on tree allometry in these nations.

Year wise publication status

Year wise classification of the data shows that there were few works in allometric equations in South Asia prior to 1950 (Fig. 2). By 1960, works in this field began to take effect in the region especially in India, Pakistan and Sri Lanka. In 1980s, tree inventory and volume table preparation at regional and national scales were taken up by all nations in South Asia and large

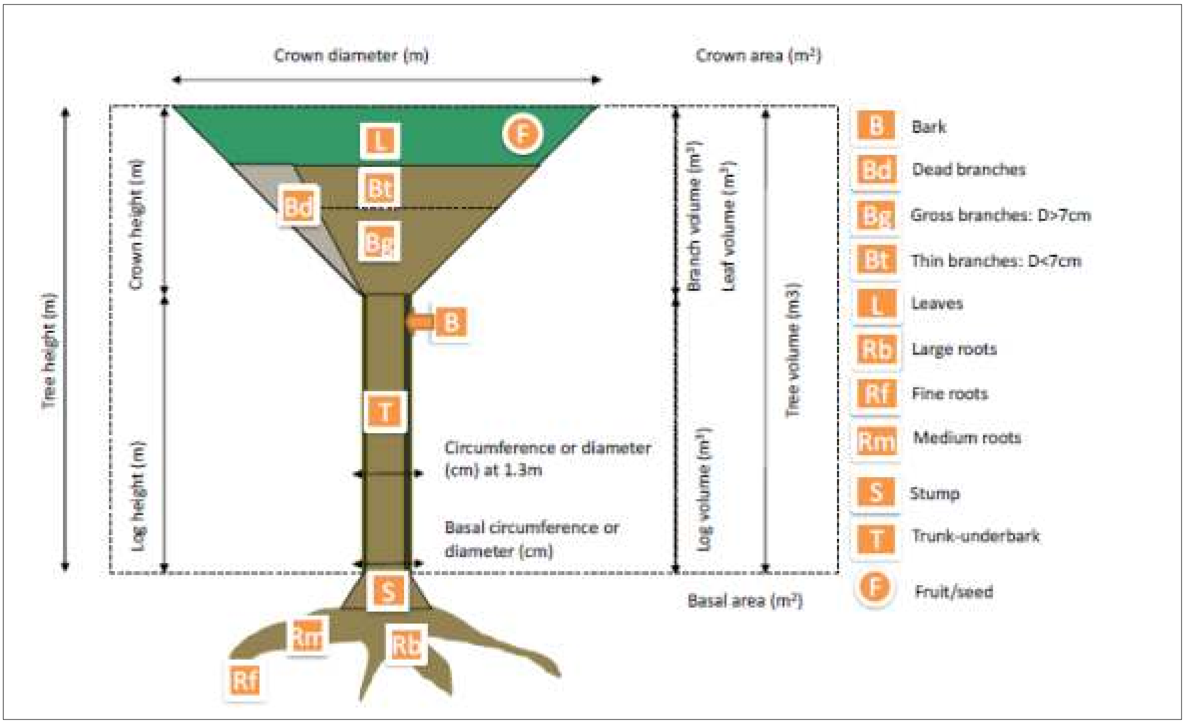

Fig. 1: Tree components classification used in the present work (Henry *et al*., 2011)

Table 2: Status of population in the literature covered

Population	Bangladesh	Bhutan	India	Nepal	Sri Lanka	Pakistan
Tree	54	9	264	27	19	8
Stand	15	1	36	7	5	4
Mangroves	2	0	2	0	1	0
Shrubs	4	3	12	0	0	1
Seedlings	1	0	12	0	0	1
Total	76	13	326	34	25	14

volumes of output were generated each year. With the advent of new century, modern techniques of inventorying were utilized on a large scale and publications in peer reviewed journals were also found to increase substantially. Since 2000, documents containing allometric equations are being published in the region at a rate of 14 per year, slightly over the 12.5 per year in the previous decade.

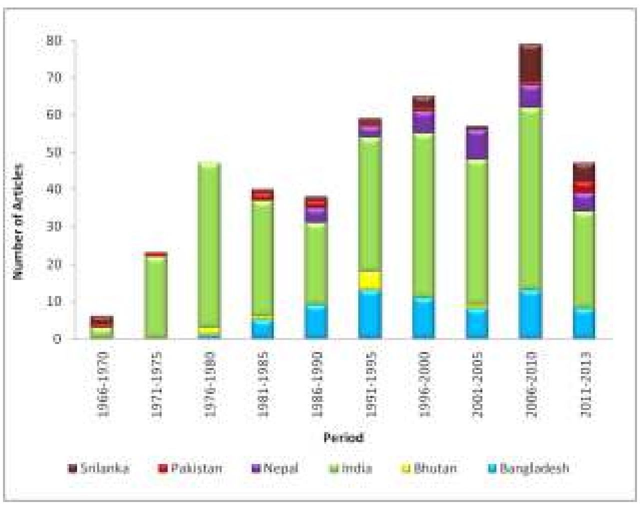

Fig. 2: Number of published literature per year in South Asia.

Population status

Population status explains whether the equations have been developed for trees or stands or mangroves or shrubs or seedlings (Table 2). 70-80% of the equations developed and literature derived from the region were

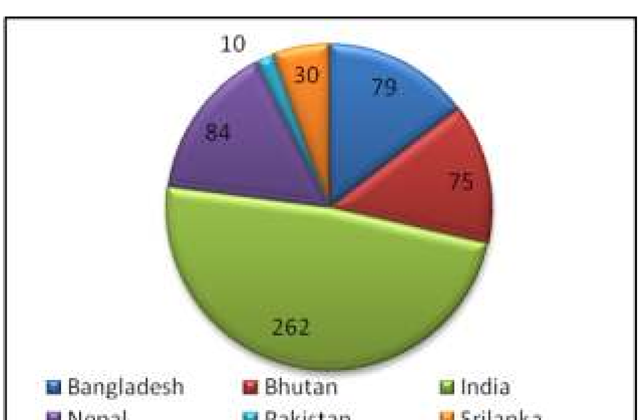

Fig. 3: Country wise coverage of tree species in the database

for tree populations (except Pakistan). Tree populations were followed by stand and shrubs in the number of equations developed in each country. Equations for mangroves, shrubs and seedlings are the least in the database with only 8% of the records corresponding to these growth forms in the database. As most of the equation in the database is with respect to trees, further discussions in the report are made with respect to this particular population.

Tree species status

The database contains allometric equations for 375 species belonging to 96 families and 275 genera and their countrywise coverage in the region is given in Table 3 and Fig. 3. Maximum number of allometric models in the database is for *Tectona grandis* covering 5.03% (*n* =224) of the total equations in the database. 4.76% (*n* = 212) equations in the database is with respect to *Populus deltoides*, which ranks second after *Tectona grandis.* 3rd, 4th and 5th positions with respect to the number of equations in the database is occupied by *Dalbergia sissoo* (*n* = 158), *Shorea robusta* (*n* = 142*) and Acacia auriculiformis* (*n* = 133). These results show the importance attached to scientific management of plantation species in the region Among the forest species maximum number of allometric equations were developed in South Asia for *Cupressus macrocarpa* (n = 144) followed by *Sonneratia apetala* (n = 84). Trees such as *Terminalia tomentosa, Syzygium cumini, Adina cordifolia, Albizia procera, Pterocarpus marsupium, Anogeissus latifolia, Lagerstroemia parviflora, Garuga pinnata, Cassia fistula, Dalbergia latifolia, Syzygium cerasoides, Holarrhena antidysenterica, Gmelina arborea etc.* though dominant in specific biomes had

Table 3: Country wise coverage of genera, family and allometric equations in the database

Country	Number		
	Family	Genus	Equations
Bangladesh	33	72	874
Bhutan	32	64	291
India	72	204	2813
Nepal	39	64	373
Pakistan	5	10	44
Sri Lanka	18	29	65

very less representation in terms of allometric equations.

Though mangroves form an important population and plays a vital role in ecological maintenance and carbon sequestration along the coastal belts of South Asia, it was found to be neglected from the purview of most allometric works in the region. Similarly home gardens and trees outside forest contribute much to the vegetation, biomass and carbon storage, but haven't gained much importance with respect to tree allometric model development in the region.

Tree components status

Tree components are considered in the equations either singly or in combination (Eg. Branch, Branch + stump + Trunk etc.). So the same equation can contain more than one tree component. 60% of the total tree allometric equations developed in the region are for stump and trunk (Fig. 4). Trunk and stump variables are easy to measure and researchers often try to relate easily measurable characters to difficult to measure ones in allometric equations. Foliage, branches, bark etc are often loosely defined and difficult to quantify, hence left out in most instances of allometric equations. Though roots form an important component of plant biomass it was found to be neglected in most documents included in the database.

Allometric equations status

A total of 4456 tree allometric equations are covered in the database. Out of these 48% are biomass equations, 40% are volume equations, 1.5% equations describes carbon stocks, 0.5% describes biomass expansion factors (BEF) and miscellaneous forms cover 10% of the equations. Among the total volume and biomass equations 53 and 77 per cent respectively were developed in India (Table 4).

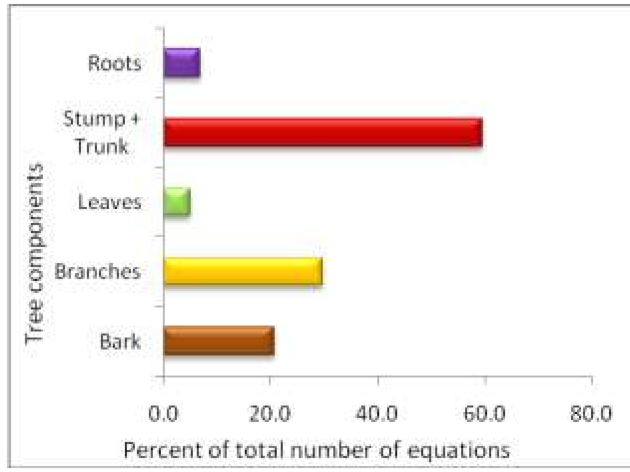

Fig. 4: Percentage of allometric equations per tree component

Geographical distribution of the equations in South Asia

There is high unevenness in the geographical distribution of equations developed across different biomes in South Asia (Fig. 5). The amount of allometric works in different life zones had a good correlation with

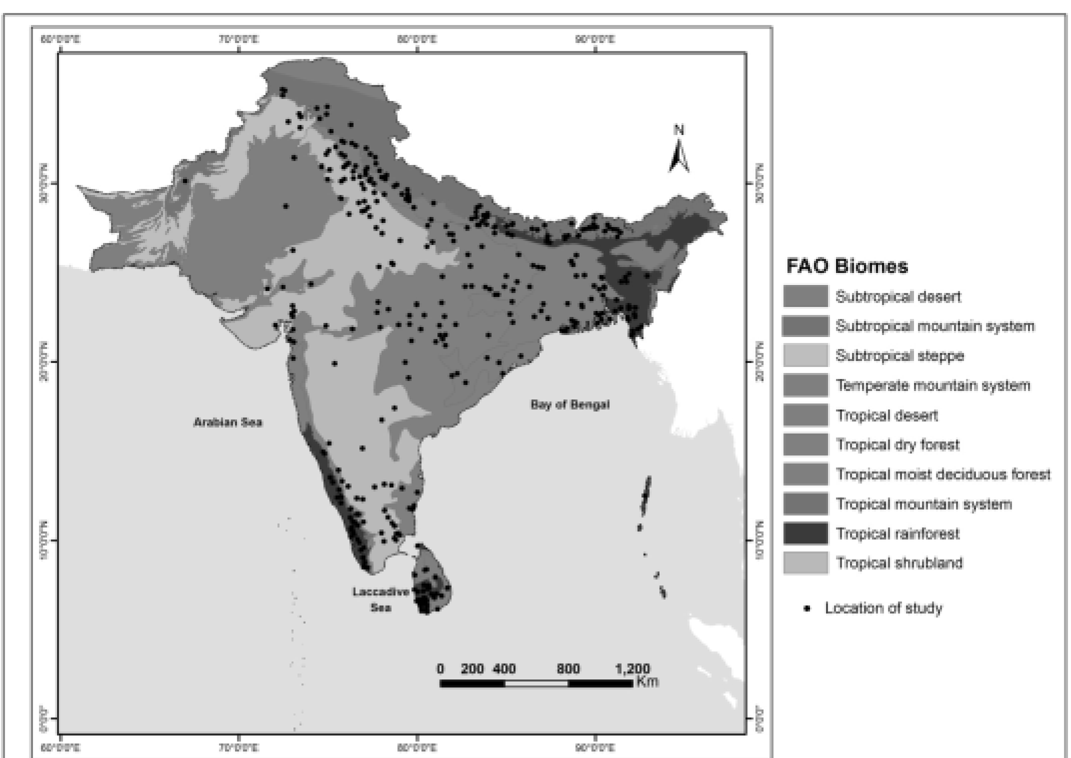

Fig. 5: Geographical distribution of sample plots in FAO Biome systems of South Asia

Table 4: Country wise status of the volume, biomass and BEF tree allometric equations in database

Country	Volume number	Biomass number	BEF number
Bangladesh	592	116	0
Bhutan	140	100	0
India	939	1671	26
Nepal	47	250	0
Pakistan	12	15	0
Sri Lanka	31	8	0
Total	1761	2160	26

Table 5: Coverage of tree allometric equations across different FAO biomes in South Asia

FAO Biomes	Species	Allometric equations
Subtropical mountain system	85	231
Subtropical steppe	3	19
Tropical desert	7	25
Tropical dry forest	52	422
Tropical moist deciduous forest	75	547
Tropical mountain system	68	167
Tropical rainforest	155	945
Tropical shrubland	95	581
Coordinates not available	260	2380
Total*	375	4456

* Total doesn't represent sum of a particular column as the same species/ allometric equation is repeated in more than one biome. Total refers to the actual number of species/ allometric equation after excluding repetitions.

diversity of the system. 21% of the allometric equations in South Asia were developed for 155 species in tropical rainforests followed by tropical shrubland which covers 95 species and 13% of the equations (Table 5). Among all forest types on earth, the greatest diversity of plants is found in tropical rainforest. Rainforests of tropical Asia are second in extent only to the range of Amazonian rainforests and are found in a great belt centred on the Malay Archipelago, but with tracts found as far west as parts of India and Sri Lanka all the way to the east in Papua New Guinea and northern Queensland in Australia and Pacific islands. Tropical regimes like tropical moist deciduous forest, tropical dry forest and tropical mountain system were also found to have good number of allometric equations. High diversity in the tropical systems compared to other life zones in South Asia can be cited as the main reason for concentration of most allometry works in these sites. Consequently, tropical desert and subtropical steppe with low species diversity have less number of allometric equations. However, systems with less plant diversity such as subtropical steppe and tropical deserts had very few allometric works. Coordinates were not available for 2379 allometric equations covered in the database.

Conclusions and recommendations

This compilation work was an attempt to inventory all available published data on tree allometric equations in South Asia. The database has been prepared by extensive and exhaustive literature collected from the region. Nevertheless, there will be several lacunae which can be progressively corrected.

An analysis of the compiled documents from the region shows that South Asia has developed 4456 equations on volume, biomass, BEF, carbon and other growth variables for 375 species belonging to 96 families and 275 genera are included in the database. Proportionate allocation of allometric models for different species in the collected documents is not homogenous with commercially important ones capturing more percentage share of equations (Eg. *Tectona grandis, Populus deltoides,* etc.). Though root biomass is as important as shoot in carbon stock estimations, there were very few documents on root growth parameters. The geographical distribution of these allometric equations is highly skewed and conscious efforts should be taken to unearth documents on allometry in the neglected life zones.

Given the high biodiversity within and among different life zones in South Asia, further scientific analysis of the allometric equations in the database is needed to derive more elaborate results. Research activities in the region should be directed to fill the existing gaps in allometric equations database. Studies should be taken up to improve the geospatial distribution of sample plots and thereby include under-represented biomes such as subtropical steppe and tropical desert (FAO biome system) in the South Asian region. Efforts to develop allometric equations of neglected tree species (eg. *Terminalia tomentosa, Syzygium cumini, Adina cordifolia,* etc.), mangroves, home gardens and trees outside forest should be taken up for a comprehensive assessment of carbon stocks in the region.

Since felling is banned in many countries, there have been difficulties in obtaining permission to fell sample trees. This discourages the researchers to take up new studies related to developing volume and biomass allometric equations. Among the population, biomass estimates are available for many shrubs and seedlings. However, such estimates are not useful for extrapolation as they lack minimum statistical measures like standard error and thus not found place in the database developed here. Similarly, there are many stand level volume equations developed, most of them are of non-linear nature and hence conceiving a common database for carbon storage estimation appears to be a difficult task.

Given the huge spatial variability of estimates of the parmeters associated with allometric equations and absence of GPS (Geographical Postioning System) measurements for large number of equations published before the advent of GPS, the calibration of the equations for carbon estimation at local and regional level has been a big issue. The availability of suitable analytical and decision support tools related to carbon issues has also been a weak area in the region. Lack of minimum publishing and reporting standards is another weakness in allometric database reporting in the region. Vague description of tree components and output terms reduces the quality of allometric equations developed in the region.

Recently there has been a considerable interest in using site and species specific allometric equations for estimating volume, biomass and carbon stocks in the region. This comprehensive repository of allometric works in South Asia will provide policy makers valuable inputs during REDD+ policy formulations in the region in tune with International standards.

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