A GIS-BASED MODEL TO IMPROVE ESTIMATION OF ABOVEGROUND BIOMASS OF SECONDARY FORESTS IN THE PHILIPPINES

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MAGCALE-MACANDONG, D. B., DELGADO, M. E. M., TY, E. & VILLARIN, J. R. T. 2006. A GIS-based model to improve estimation of aboveground biomass of secondary forests in the Philippines. A geographic information system (GIS)-based model was developed to spatially predict the aboveground biomass of secondary forests in the Philippines. A database of the physical (soil type, slope, elevation) and climatic (agroclimate zone, annual rainfall) properties of the different administrative units (provinces) in the country was assembled from secondary data and existing maps. Thematic maps of each of the above physical and climatic properties were developed for the whole country. Published data on diameter at breast height (dbh) of sampled trees in secondary forests, and plantations of *Swietenia macrophylla* and *Dipterocarpus* sp. were used to estimate aboveground biomass using allometric regression equation. The relationship of the physical and climatic factors (independent or predictor variables) and the forest aboveground biomass (dependent variable) was determined through multiple linear regression analysis. The resulting equation was used to predict potential aboveground biomass of secondary forests in the country. Overlaying the potential biomass map to the remaining secondary forest areas resulted in a map of the estimated aboveground biomass of secondary forests. The study demonstrated the potential of GIS in estimating forest biomass at different locations and environmental conditions. The GIS-based model can be further improved with the availability of tree biomass data and digital maps.

Keywords: Allometric equation, multiple linear regression, *Swietenia macrophylla*, *Dipterocarpus* sp., C stocks, GHG inventory

MAGCALE-MACANDONG, D. B., DELGADO, M. E. M., TY, E. & VILLARIN, J. R. T. 2006. Model berasaskan GIS bagi memperbaiki anggaran biojisim atas tanah hutan sekunder di Filipina. Satu model berasaskan sistem maklumat geografi (GIS) dikembangkan untuk menganggar ruang biojisim atas tanah hutan sekunder di Filipina. Satu pangkalan data ciri-ciri fizikal (jenis tanah, cerun, ketinggian) dan iklim (zon agroiklim, hujan tahunan) bagi unit pentadbiran (wilayah) yang berlainan di dalam negara dibentuk daripada data sekunder dan peta-peta yang sedia ada. Peta tema bagi ciri-ciri fizikal dan iklim di atas diasaskan untuk seluruh negara. Data terbitan bagi diameter pada paras dada (dbh) untuk pokok-pokok di dalam hutan sekunder dan ladang-ladang *Swietenia macrophylla* dan *Dipterocarpus* sp. digunakan untuk menganggar biojisim atas tanah menggunakan persamaan regresi alometrik. Hubungan antara faktor-faktor fizikal dan iklim (pemboleh-pemboleh ubah tak bersandar atau ramal) dengan biojisim atas tanah hutan (pemboleh ubah bersandar) ditentukan menggunakan analisis regresi linear berbilang. Persamaan yang didapati digunakan untuk menganggar potensi biojisim atas tanah bagi hutan sekunder di dalam negara. Penindihan peta biojisim berpotensi dengan peta kawasan hutan sekunder yang tinggal menghasilkan peta anggaran biojisim atas tanah bagi hutan sekunder. Kajian ini menunjukkan potensi GIS dalam menganggar biojisim hutan pada lokasi dan keadaan persekitaran yang berbeza. Model berasaskan GIS boleh diperbaiki lagi dengan adanya data biojisim pokok dan peta digital.

Introduction

Estimates of biomass are vital in the determination of carbon stocks of terrestrial ecosystems. Forests contain 90% of all the carbon in terrestrial vegetation (Dale *et al.* 1994). There is a need to improve prediction of aboveground biomass in forests as errors in estimating the aboveground biomass of this ecosystem cause large uncertainties in the carbon budget.

The total forest cover of the Philippines as of 2000 has been estimated at 15.8 Mha, equivalent to 53% of the country's total land area of 30 Mha (FMB 2000). Liu *et al.* (1993) reported that an estimated 9.8 Mha of forest has been lost from 1934 to 1988, or an annual average deforestation rate of 0.18 Mha. Massive deforestation in the last quarter of the century has fragmented forest areas with dipterocarp and pine forests now occupying 3.54 and 0.23 Mha respectively and secondary forests occupying an estimated area of 2.74 Mha (FMB 2000). These forest areas comprise the largest

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remaining natural forest type in the country, and much have been cleared during the last century due to shifting cultivation, squatters and the migration of landless lowlanders to upland forested areas. Secondary forest areas are under severe pressure from human activities as it is the main source of wood and other forest-based resources.

Under the United Nations Framework Convention on Climate Change (UNFCC), participating countries are required to report national inventory of greenhouse gas (GHG) emission or uptake. The Kyoto protocol of the UNFCC requires full carbon accounting and verifiable changes in carbon stocks during the commitment period (Lebre la Rovere & Ravindranath 1999). The current challenge now is to reduce these uncertainties and produce accurate and reliable activity data and emission factors essential in reporting national (GHG) inventories. Improvements in aboveground biomass estimation can also help account for changes in carbon stocks in forest areas of tropical countries such as the Philippines that may potentially participate in the Clean Development Mechanism (CDM) under Article 12 of the Kyoto Protocol.

Several studies have estimated the aboveground biomass density of forests in South-East Asian countries including the Philippines using various approaches. Iverson *et al.* (1994) developed a geographic information system to estimate total biomass and biomass density of tropical forests in South and South-East Asia. This will be potentially useful to C stocks accounting in the region since available data from forest inventories were insufficient to extrapolate biomass density estimates across the region. The study predicted the potential biomass density of tropical forest without human intervention or natural disturbances. This value was derived from overlaying data on elevation, soils, slope, rainfall and an integrated climate index using geographic information system (GIS). Results showed that the average potential biomass density (without human influences) for nine countries was estimated to be 370 t ha^{-1} and the actual biomass density (with human influences) was equal to 194 t ha^{-1}.

Iverson *et al.* (1994), Flint and Richards (1994), and Hall and Uhlig (1991) conducted studies to estimate country-specific aboveground biomass for the Philippines, with 1980 as the baseline year. Data showed variation in estimates across studies where Iverson *et al.* (1994) predicted 223 t ha^{-1} biomass density for Philippine forests. The biomass density values that Flint and Richards (1994) reported ranged from 152 to 179 t ha^{-1}, while Hall and Uhlig (1991) ranged from 134 to 353 t ha^{-1}. FAO (1997) reported estimates of potential biomass density of 511 t ha^{-1} and an actual biomass density of 223 t ha^{-1} for secondary forests in the Philippines using the methodology of Iverson *et al.* (1994). Values estimating aboveground biomass using global land use models (Palm *et al.* 1986, Houghton *et al.* 1997) are usually higher because areas are classified by wide-ranging ecological categories. Estimates using global land use models reach 500 t ha^{-1} for moist tropical forest and 300 t ha^{-1} for seasonal tropical forests.

Dale *et al.* (1994) explained that the variations in many countries' estimates resulted from three factors: (1) the classifications of forest categories are not directly comparable across the studies, (2) varying methods used to account for forest degradation from human activities influence the magnitude of the estimates and (3) the differences in the assumptions regarding the potential biomass that can be supported by a region.

The use of GIS technology offers an approach to develop a biomass map of forests (Iverson *et al.* 1994) for regions with little data. GIS allows the incorporation of spatial heterogeneity into the modelling process and offers a method for estimating biomass density at a continental scale where forest data are lacking in most areas and humans have disturbed most forest lands. It can be extended to areas in which data are not available because consistent patterns of biomass density frequently result from similar biophysical characteristics in the study area. A geographically referenced biomass density database for tropical forests would reduce uncertainties in estimating annual biomass increment and forest aboveground biomass.

The main objective of this study was to develop a methodology to improve estimates of forest aboveground biomass in the Philippines using a GIS-based modelling approach. The specific objectives were to collect secondary data for the Philippines (climate, agroclimate zone, soil type, slope, elevation) that will be needed in the GIS modelling and to develop a GIS-based model that could be used to predict estimates of aboveground biomass of secondary forests at different locations and environmental conditions in the Philippines.

Methodology

Study area

The Philippines is a tropical country located between the equator and the Tropic of Cancer in the South-East Asian region. The main types of forest vegetation found in the country are dipterocarp, mangrove, pine and mossy forests.

Physical and climatic database

The validity of the results of this study is highly dependent on the availability and reliability of data upon which this work is based. The major part of the study is the acquisition and pre-processing of suitable data needed for the analyses. Data were acquired from published papers, research results, various surveys and reports of different government agencies in the Philippines.

A database of physical and climatic characteristics (soil type, slope, elevation, agroclimatic zone and rainfall) of forest areas of the different provinces in the country was developed. The forest areas in each of the provinces were delineated based on the Bureau of Soils and Water Management (BSWM 1975) land use map (1:1.5 million scale). At the time of this study, this large-scale map was the only land use map available in the country. The dominant soil type of forest areas in each province was extracted from the provincial reconnaissance soil survey maps (1:500 000) developed by the Bureau of Soils and Department of Agriculture (Fernandez & Clar de Jesus 1980). The codes assigned for the different soil types in the database are shown in Table 1.

The slope of forest areas was based on the slope maps (1:1.75 million) generated by the BSWM (1975). Six slope categories: level to nearly level (0–3%), gently sloping to undulating (3–8%), moderately sloping to rolling (8–15%), steeply rolling (15–30%), mountain (> 65%) and swamps were identified in the slope maps. The slope value of the major portion of forest areas in each province was entered in the database (Table 1).

The data for elevation of forest areas in each province was extracted from the national elevation map (1:50 000) developed by the National Mapping and Resource Information Authority (NAMRIA 1995). The range of elevation of forest areas in the different provinces is found in Table 1.

The forest agroclimatic zone data (1:1.5 million) were acquired from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA 1990). Thirteen agroclimatic zones were identified (Table 1) based on the number of dry and wet months. Climatological normals from PAGASA (1961–1995) were also obtained to determine the annual rainfall (mm) of forest areas in each province.

Secondary forest biomass determination using allometric equation

Data for diameter at breast height of sampled tree species were acquired from Lasco *et al.* (2001), Guillermo (1998) and Racelis (2000) (Table 2). The three datasets were obtained from sample plots (0.05–0.4 ha) in secondary forests and *Dipterocarpus* and *Swietenia* plantation forests in Mt. Makiling, Subic and Quezon National Park. A total of 630 trees with dbh ranging from 5–179 cm were measured in the three studies (Table 2).

Estimates of aboveground biomass were calculated from the dbh data using the allometric regression equation developed for secondary forests in the Philippines. The allometric regression is a power equation:

$$B = 0.0679\, D^{2.496} \qquad \text{(Equation 1)}$$

where

B = aboveground biomass of tree (kg)

D = diameter at breast height (cm)

Table 1 Codes, units and description of physical data sets used in the database

Parameter	Code	Description
Soil type	1	sandy loam/ sandy clay
	2	loam/ silt loam
	3	clay loam/ silty clay loam
	4	clay
Agroclimatic zone	1	greater than 6 dry months, less than 3 wet months
	2	5–6 dry months, less than 3 wet months
	3	2–4 dry months, less than 3 wet months
	4	less than 2 dry months, less than 3 wet months
	5	5–6 dry months, 3–4 wet months
	6	2–4 dry months, 3–4 wet months
	7	2 dry months, 3–4 wet months
	8	5–6 dry months, 5–6 wet months
	9	2–4 dry months, 5–6 wet months
	10	2 dry months, 5–6 wet months
	11	2–4 dry months, 7–9 wet months
	12	less than 2 dry months, 7–9 wet months
	13	less than 2 dry months, greater than 9 wet months
	Unit	Range of values
Slope	%	0–65
Elevation	m	0–2400
Rainfall	mm	950–3855

Independent variable weight determination

A matrix of estimated aboveground biomass density of the secondary forests and the corresponding physical and climatic characteristics of the sites (soil type, per cent slope, elevation, agroclimatic zones, annual rainfall) of the three studies cited above was assembled (Table 3). These data sources were the only available literature in the Philippines reporting biomass density of secondary forests and plantation forests. The matrix was used to establish a relationship of the physical and climatic factors (independent or predictor variables) and forest aboveground biomass (dependent variable) through multiple linear regression (MLR) analysis. The regression analysis was done to determine the relative independent contribution (weights) of each physical and climatic factor to the prediction of biomass using the equation:

$$B = a + \_{1}X_1 + \_{2}X_2 + \ldots \_{n}X_n \qquad \text{(Equation 2)}$$

where

B = aboveground biomass of tree (kg)
a = intercept
_ = beta coefficients (weight of physical and climatic factor)
X = physical or climatic factor

Table 2 Site characteristics of the data sources used in the forest biomass estimation using allometric equation

Source	Site No.	Location	Forest type	Plot size (ha)	No. of trees	Dbh range (cm)	Dominant tree species
Lasco *et al.* (2001)	1	Subic	Secondary	0.4	33	30.4–179.0	*Dipterocarpus* sp., *Shorea* sp.
	2	Makiling	Secondary	0.4	68	30.0–123.0	*Diplodiscus paniculatus, Bischofia javanica*
	3	Quezon	Secondary	0.4	69	30.0–105.0	*Tristania dicorticata, Dipterocarpus* sp.
Racelis (2000)	1	Makiling	Mahogany plantation	0.05	93	5.0–74.0	*Swietenia* sp.
	2	Makiling	Dipterocarp plantation	0.05	146	5.0–74.0	*Dipterocarpus* sp.
Guillermo (1998)	1	Makiling	Secondary	0.3	221	5.0–116.0	*Celtis luzonica, Dipterocarpus* sp.

Generation and calibration of biomass map

A digitized map of the Philippines showing provincial boundaries was acquired from NAMRIA (1996). Data on prevailing climatic, edaphic and topographic conditions of forest areas were entered per province (polygon) in the physical and climatic database. Thematic map for each factor was done using a vector-based GIS software package.

Biomass of secondary forests was predicted using multiple linear regression equation (Eqn. 2) by multiplying the actual or coded values of each physical factor to its corresponding weight and summing these to yield the estimated biomass density per province. The resulting values were used to generate a spatial representation of the predicted aboveground forest biomass at provincial level.

To delineate the estimates of secondary forest areas, the resulting biomass map was intersected in GIS with the digitized land use map (1:50 000) of the Philippines (NAMRIA 1996) showing locations of secondary forests. Preliminary results of the intersection process were compared with available data from the literature on estimates of aboveground biomass of tropical secondary forests. Calibration was done by subsequent adjustments to yield the most satisfactory map based on expert judgment (consultation with experts on GIS and land use map of the Philippines) and available data. The diagram of steps taken to generate the forest biomass map is shown in Figure 1.

Results and discussion

Tree diameter at breast height (D) data from Lasco *et al.* (2001), Racelis (2000) and Guillermo (1998) for secondary forests were used to compute the aboveground biomass of trees using Eqn. 1 (Table 2). Sites 1 and 3 of Lasco *et al.* (2001) are found in Subic and Quezon respectively, with a clay loam/silty clay loam soil type and an average annual rainfall range of 1800 to 2397 mm. Site 2 of Lasco *et al.* (2001) and all the sites of Racelis (2000) and Guillermo (1998) are found at the Makiling Forest Reserve in Laguna, with clay and clay loam/silty clay loam soil types and an average annual rainfall range of 1913 to 2397 mm. The range of D for all sites was from 5 to 179 cm. The major tree species measured in the sites were dipterocarps and mahogany (*Swietenia* sp.).

Table 3 Matrix of estimated aboveground biomass density and corresponding site physical and climatic characteristics

Source	Estimated biomass density (t ha^{-1})	Soil type (code)	Elevation (m asl)	Rainfall (mm yr^{-1})	Climate (code)	Slope (%)
Lasco *et al.* (2001)						
Site 1a	205.860	3	394	1800	5	12
Site 1b	229.490	3	200	1800	5	12
Site 2a	510.170	4	260	1913	13	1.5
Site 2b	357.050	4	230	1913	13	1.5
Site 3a	326.880	3	170	2200	11	24
Site 3b	371.290	3	340	2397	11	24
Racelis (2000)						
Site 1a	181.720	3	199	2397	11	23
Site 1b	539.760	3	199	2397	11	23
Site 1c	291.080	3	199	2397	11	23
Site 2a	276.090	3	110	2397	11	12
Site 2b	317.350	3	110	2397	11	12
Site 2c	235.250	3	110	2397	11	12
Guillermo (1998)						
Site 1a	412.600	3	400	2200	11	24
Site 1b	251.670	3	400	2200	11	24
Site 1c	176.730	3	400	2200	11	24

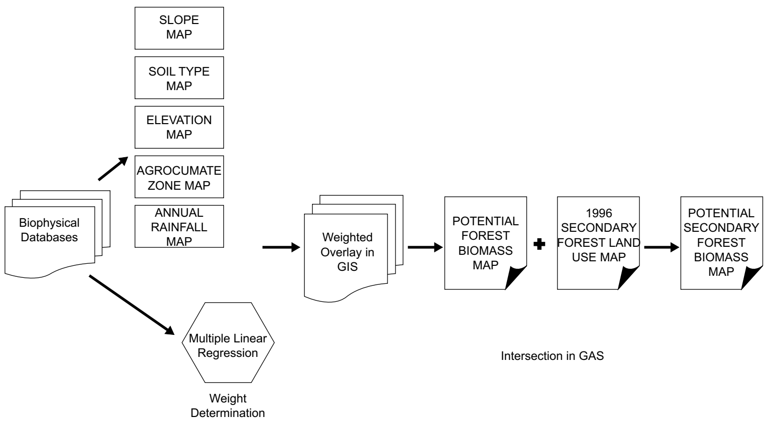

Figure 1 Flow diagram of GIS-based modelling approach for generating secondary forest biomass maps

Maps of major soil types, per cent slope, elevation, agroclimatic zones and annual rainfall of secondary forest areas per province were generated using Arcview GIS v.3.2 from the physical and climatic database developed. Each of the thematic maps was given a weight based on MLR analysis of the matrix of the estimated aboveground biomass and corresponding physical attributes. The resulting weights of each factor contributing to the prediction of biomass are shown in Table 4.

The major soil type of secondary forests in the Philippines (Figure 2a) was clay, amounting to 70.7% of all entries in the soil database. The remaining 30% was distributed to clay loam and silty clay loam soil types (17.3%), loam and silt loam types (9.3%), and sandy loam to sandy clay types

(2.7%). Soil texture influences biomass production of forests because of its relationship with soil-moisture condition, nutrient storage capacity and organic matter content. Generally, forest soils are high in organic matter from constant litterfall input.

Forest areas in the Philippines were generally found in all elevation ranges shown in Figure 2b. However, majority of forests were in the 763–1752 m (55%), and less than 10% were found in 305–533 m elevation class. Vegetation types commonly found in areas with altitude higher than 1500 m were natural grasslands and mossy forests. About 57% of the remaining secondary forest areas were found in the 30–65% slope class (Figure 2c). These areas have remained forested because agricultural production and other land uses for economic purpose are difficult at steep slopes. The remaining 43% of secondary forest areas were found in the other slope classes.

The annual rainfall values of the majority of the secondary forests were greater than 1500 mm year^{-1} (Figure 2d). Data showed 37% of the secondary forests had 2810–3858 mm year^{-1} rainfall, 21% had 2299–2809 mm year^{-1} and the remaining proportion was variably distributed over the entire range of rainfall values. Twenty-seven per cent of the forest areas were under climate type with less than 2 dry months and 7–9 wet months, 19% were of climate type with 2–4 dry months and 5–6 wet months, and 13% were under climate type with 5–6 wet and dry months (Figure 2e).

The mean potential aboveground biomass of secondary forest in the Philippines from all provinces was 355.46 t ha^{-1} (n= 75 provinces), with values ranging from 107.91 to 511.56 t ha^{-1}. Country-specific aboveground biomass estimates in Philippine forests are mostly obtained from published literature based on destructive sampling and volumetric approaches. Biomass production of forests varies by geographic region, life zone, forest type, forest structure and degree of disturbance (Brown *et al.* 1989). Results from this paper are based from studies done in the Philippines and are comparable to other studies (Table 5). Direct measurements of aboveground biomass of tropical forests in South-East Asia have values ranging from 349 to 359 t ha^{-1} (Brown & Lugo 1984) and 245–513 t ha^{-1} (Brown *et al.* 1989). Data estimated from published literature yielded ranges of 80 to 369 t ha^{-1} (Brown & Lugo 1982) for tropical and subtropical forests in various life zone groups. Default values for natural forests of insular Asia from the Intergovernmental Panel on Climate Change (Houghton *et al.* 1997) gave an estimate of 175–275 t ha^{-1}, depending on the type of forest, and for country-specific estimates the same report gave a range of value from 300–370 t ha^{-1} for Philippines' logged dipterocarp forests. The values in Table 5 were used as guide in subsequent adjustments to yield the most satisfactory map.

Table 4 Weight of each physical and climatic factor resulting from multiple linear regression analysis (R^2= 92.50)

Physical and climatic factor	Weight
Annual rainfall	-0.1033
Climate	17.1668
Elevation	-0.1621
Slope	3.66446
Soil type	108.2441

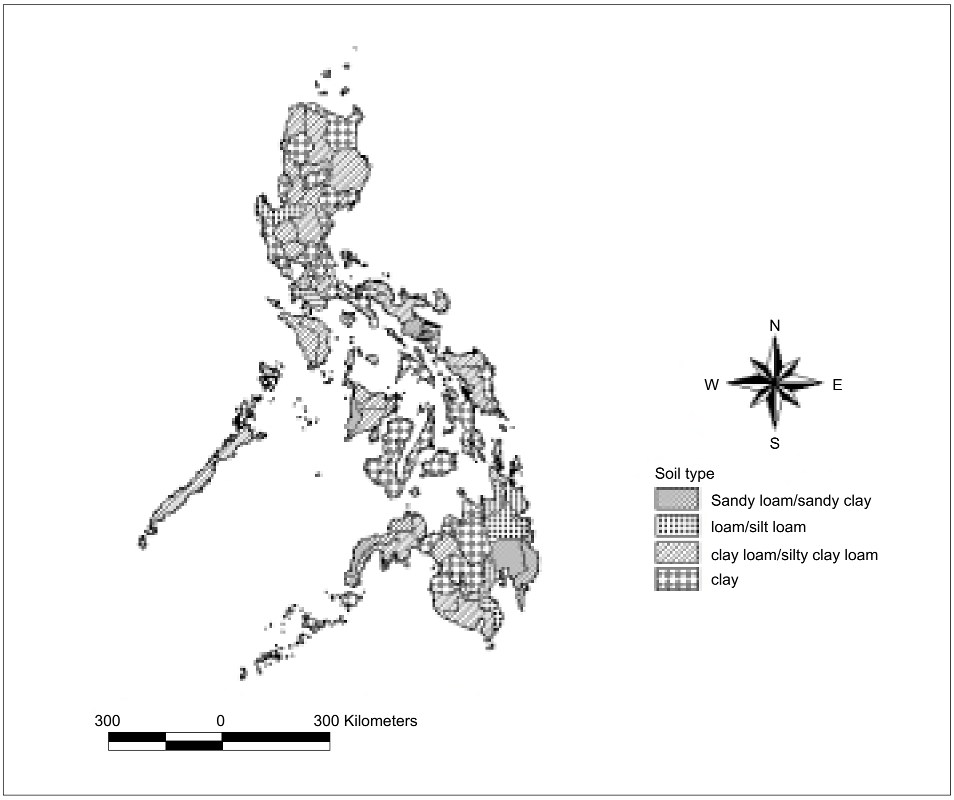

Figure 2a Major soil type of secondary forest areas in each province in the Philippines

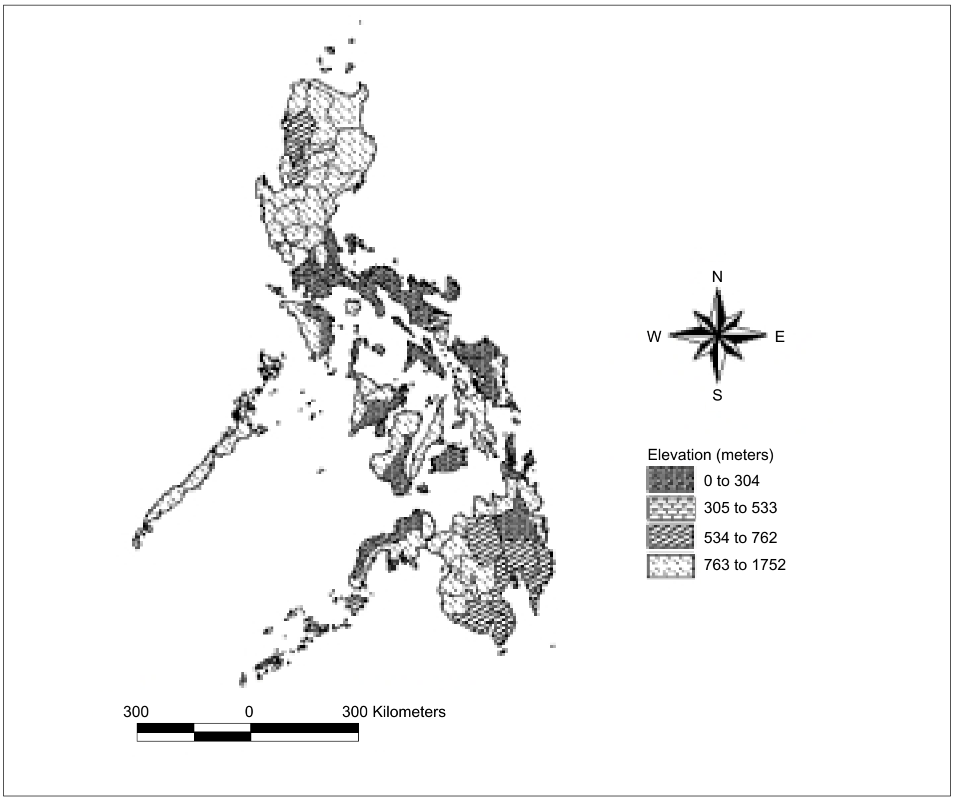

Figure 2b Elevation ranges of secondary forest areas in each province in the Philippines

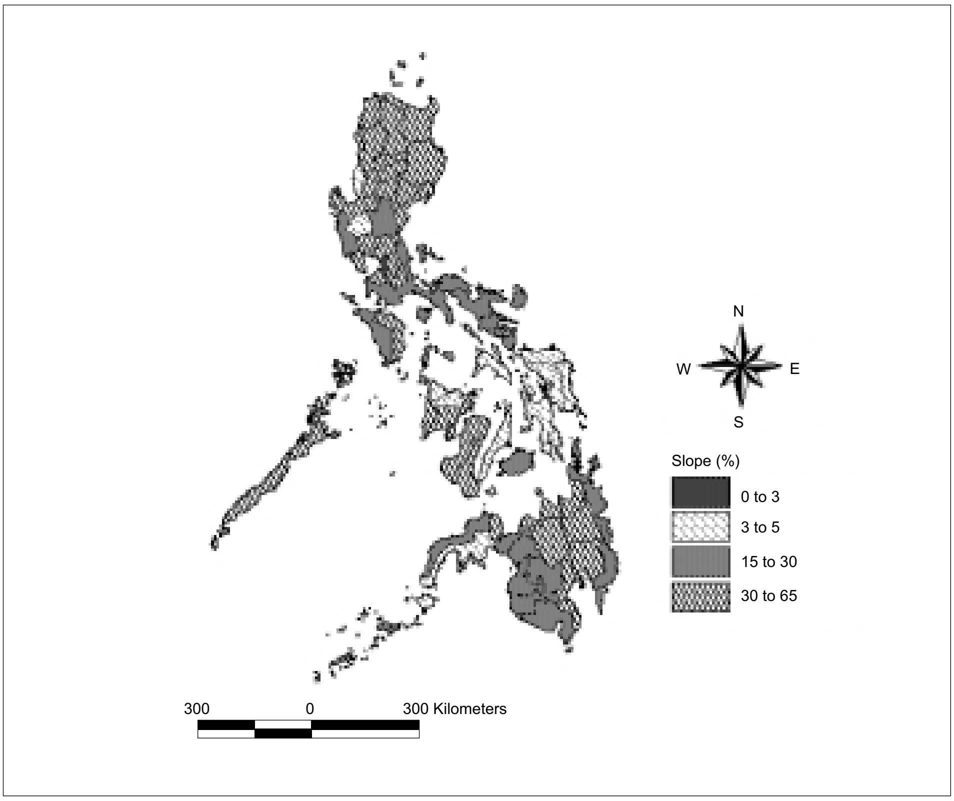

Figure 2c Slope ranges of secondary forest areas in each province in the Philippines

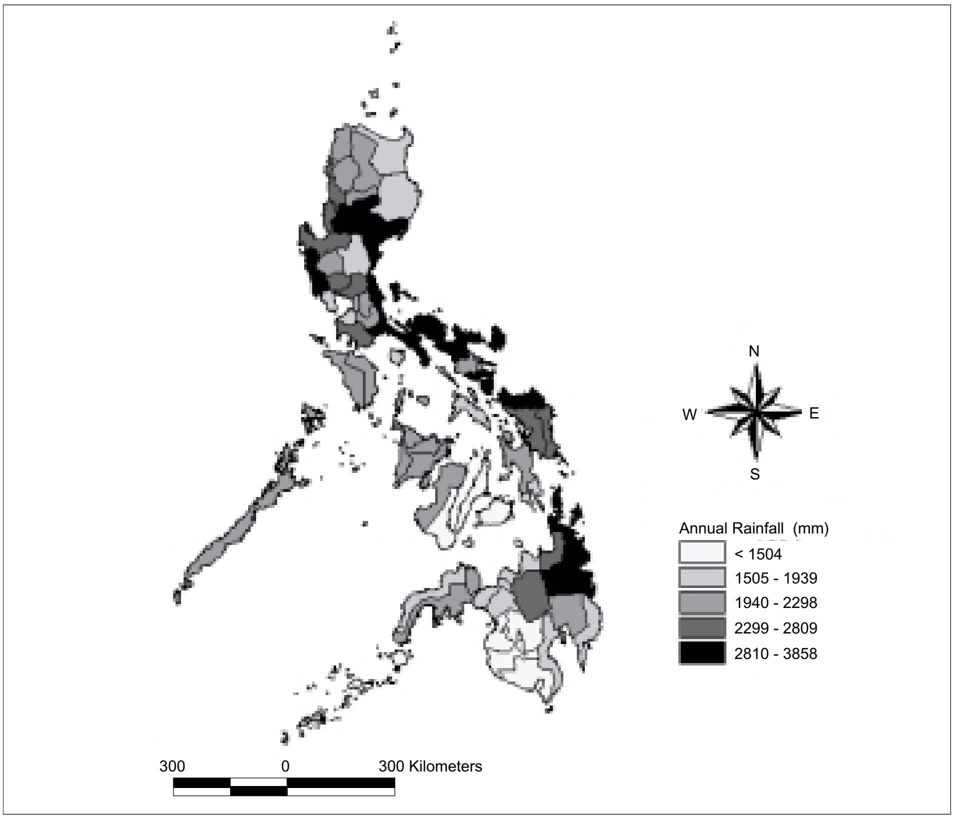

Figure 2d Annual rainfall ranges of secondary forest areas in each province in the Philippines

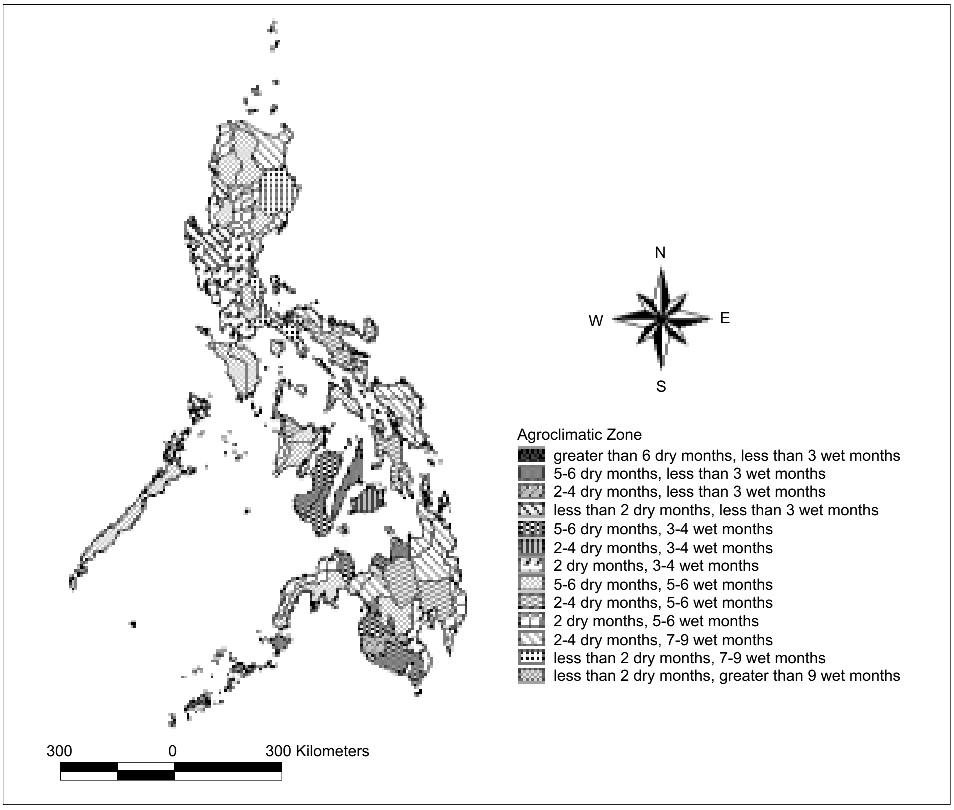

Figure 2e Agroclimatic zone of secondary forest areas in each province in the Philippines

Table 5 Estimated aboveground biomass (t ha^{-1}) of secondary forests (1980) in the Philippines reported by different sources using different methodologies

Estimated aboveground biomass (t ha^{-1})	Source
223	Iverson *et al.* (1994)
152–179	Flint & Richards (1994)
134–353	Hall &Uhlig (1991)
511	FAO 1997

The potential aboveground biomass map in each province is shown in Figure 3. Based on major climatic, edaphic and topographical characteristics of secondary forest areas per province in the Philippines, the results showed that high biomass estimates could be found in the provinces of Cagayan, Zamboanga del Norte and del Sur, Panay island and Bohol, with values ranging from 467 to 512 t ha^{-1}. Provinces with mid-range biomass values (250–350 t ha^{-1}) included Quirino, Cagayan de Oro, Albay, Camiguin, Nueva Vizcaya, Basilan and Surigao del Norte. The lowest predicted biomass densities were recorded for the provinces of Pangasinan, Benguet, Sorsogon, Tarlac, Camarines Sur, Batangas and Davao del Sur, with values ranging from 108 to 200 t ha^{-1}.

Overlaying the provincial potential biomass map (Figure 3) to the remaining secondary forest areas reported in the 1996 NAMRIA land use map resulted in a map of the estimated aboveground biomass occurring on the remaining areas under forest (Figure 4). In general, the remaining secondary forest areas in the Philippines were estimated to have relatively high biomass density values. Figure 4 shows the prominence of forest areas with high aboveground biomass estimates (401–500 t ha^{-1}) scattered in Luzon, Visayas and Mindanao, the three major islands of the Philippines.

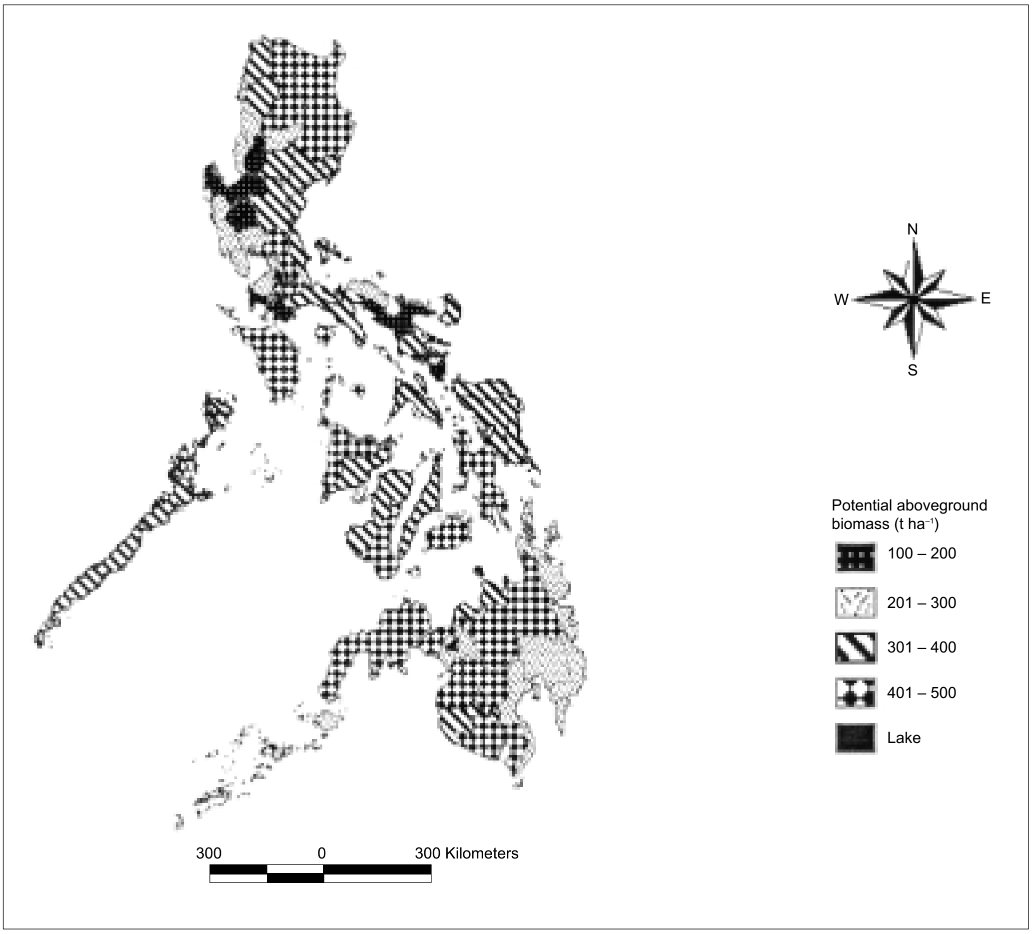

Figure 3 Potential aboveground biomass (t ha^{-1}) of secondary forests in each province in the Philippines

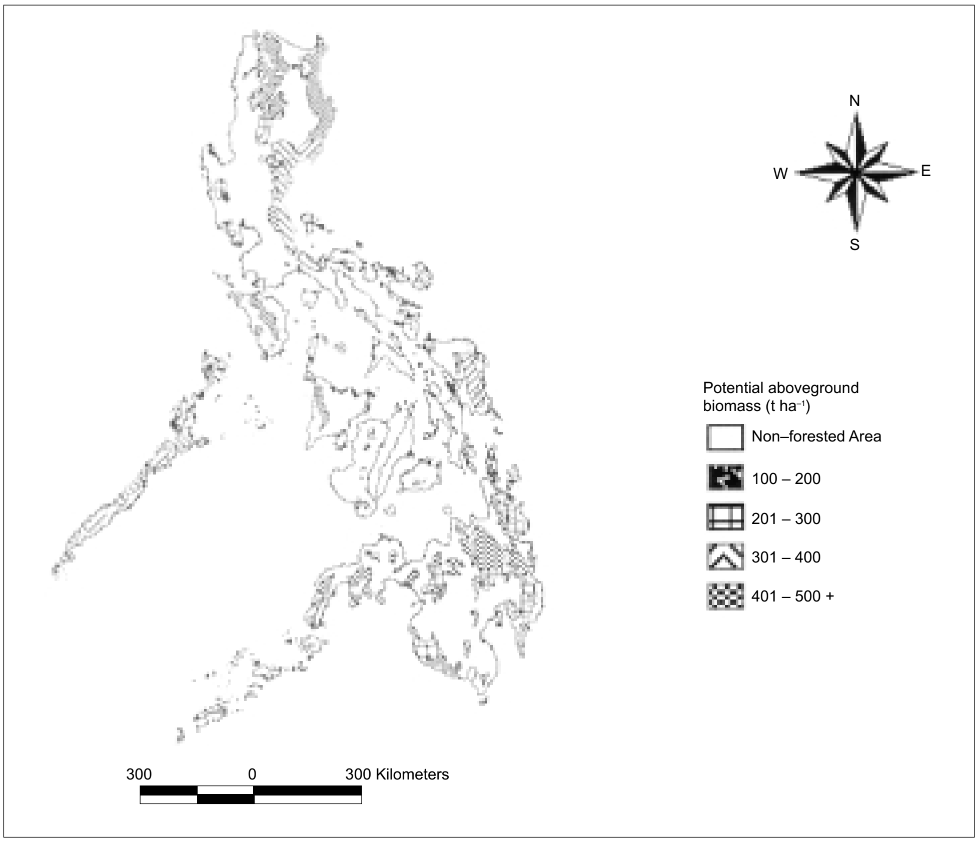

Figure 4 Potential aboveground biomass (t ha^{-1}) of remaining secondary forests in each province in the Philippines.

The islands of Mindoro and Palawan, where many endemic floral and faunal species are found, showed potential forest biomass estimates ranging from 301–400 and 401–500+ t ha^{-1} respectively dominating the landscape. Areas with high agricultural activity and urbanization showed low or no forest cover at all, although these areas can potentially carry 200 to 500 t ha^{-1} of forest biomass. These areas include the islands of Cebu, Bohol, Leyte, Negros, Panay and Masbate.

The total estimated biomass of secondary forests at a national scale was determined by multiplying the potential provincial biomass density derived from this paper and from available literature (Table 6) to the total forested area per province (FMB 1997). Figure 5 shows the varying total national biomass estimates using biomass densities from different sources. The estimated national biomass using the provincial biomass densities from this paper is the highest with 5.5 million tons of forest biomass. Data from Lasco (1998), Francisco (1996) and UNDP-ESMAP (1992) yielded 3.8, 4.9 and 4.4 million tons respectively.

The approach developed in this study show the potential to improve the accuracy of secondary forest biomass estimates at the national level. Estimating forest biomass at the provincial level takes into account local variations in environmental factors and ecological zones affecting tree growth and thus forest biomass.

Conclusions and recommendations

This study demonstrated the potential of using GIS approach in estimating aboveground biomass and improving the quality of biomass estimates. The GIS-based model can be used to predict aboveground biomass of secondary forests at different locations and environmental conditions in the Philippines. This will greatly improve the computations for the C stocks present in secondary forests as well as preparation for the national GHG inventory report. The GIS-based model presented here can be further improved with the availability of digitized maps for the different physical or environmental characteristics (dependent variables) for the whole country that can be used to estimate aboveground biomass (dependent variable).

The application of the GIS approach allowed the spatial extrapolation of forest aboveground

Table 6 Biomass density values (t ha^{-1}) of secondary forests in the Philippines as reported by different authors (adapted from Magcale-Macandog 2000).

Source	Biomass density
Lasco (1998) and Philippine National GHG Communication (2000)	258
Philippine Inventory of GHG emissions and sinks: 1990 (Francisco 1996)	335
UNDP-ESMAP (1992)	300

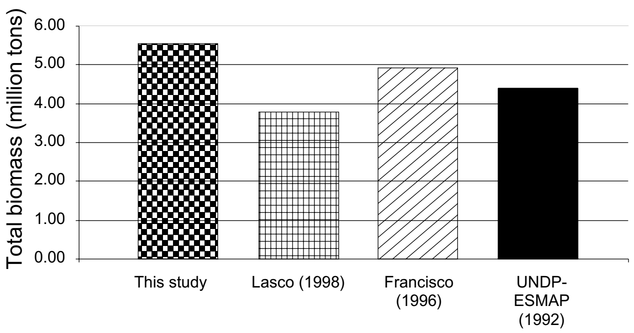

Figure 5 Comparison of estimates of total secondary forest biomass (million tons) in the Philippines from different sources and this study

biomass to areas where data are limited or lacking. However, the validity of the results is very much determined by the availability and reliability of data. The limitation of this study is the lack of available data and literature on secondary forest biomass under different environmental conditions or ecological zones in the country. Improvements to this approach can be achieved with further research on other factors that influence biomass production in forests and should be included in future estimates. Enhancing the resolution of input maps and the incorporation of more recent GIS techniques as the technology advances can reduce variability of biomass estimates at the local level. Validation should follow whenever new data are available.

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