Indonesian Soil Data Base and Predicted Stock of Soil Carbon

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Abstract: Indonesian soil data collection has been carried out for more than a hundred years. However, a digital soil database management (SDBM) system of ICALRD was just started around the 80's. Since then, a large number of digital data in spatial, tabular and metadata formats have been collected and generated. There are some application softwares of soil database to manage such a large amount of data, i.e. : Side & Horizon (SHDE4), Soil Sample Analysis (SSA), and Land Unit in dbf file, while Site and Horizon is in DataEase formats. The database contains soil physics and chemical property data of each soil horizon from surface to effective soil depth, climate, land surface conditions, and other parameters required for soil classification. Until now, soil identification and mapping in Indonesia has covered about 72% of the whole land area at the 1:250.000 scale and about 21% at higher scales. But about 10% of the soil inventory and mapping data based on surveys earlier than 1988 have not been digitized yet. Soil organic carbon, C_{org}, and soil bulk density, BD (the two parameters required for calculating soil carbon stock) data are also stored in the database, but only less than 10% of the surveys included bulk density data. Therefore, our approach is to use BD data from various research of the similar soil type. We assess soil organic carbon stock of the 0-30 cm for Indonesia based on site-specific and generalized BD data and site specific data of soil organic carbon. We came up with BD of 0-30 cm soil depth for Oxisols, Ultisos, Andisols, Inceptisols and Spodosols of (Mg m^{-3}) 1.04 $\pm$ 0.18, 1.16 $\pm$ 0.11, 0.80 $\pm$ 0.05, 1.16 $\pm$ 0.16, 0.97 $\pm$ 0.17, respectively. Unavailable data of BD are for Alfisols, Entisols, Mollisols, and Histosols, and based on various_ research reports we found the BD of these soils of 1.23 $\pm$ 0.08, 1.18 $\pm$ 0.24, 1.34 $\pm$ 0.10, 0.44 $\pm$ 0.04 Mg m^{-3}, respectively The respective C_{org} of these soils are about 2.06 $\pm$ 1.15, 1.86 $\pm$ 1.38, 5.24 $\pm$ 4.17, 2.34 $\pm$ 1.57, 3.16 $\pm$ 2.54, 1.43 $\pm$ 0.73, 3.18 $\pm$ 2.45, 42.08 $\pm$ 10.23, and 3.28 $\pm$ 1.75 % (by weight). Thus, based on the availability of data, estimated national carbon stock of 0-30 cm depth for the 162 million ha mineral soil is around 17.6 Gt for 81.5% of land (soil data of 18.5% area is not available). For peat soil, organic matter is high throughout the profile. With an estimate of 50 kg C m^{-3} of peat soil, the first 30 cm peat layer of the 21 million ha Indonesian peat land stocks around 3.15 Gt C.
Keywords: Indonesian soil database, Soil Carbon stock, Soil organic Carbon, Bulk Density.

1. Introduction

In this paper, soil is defined as a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment (Soil Survey Staff, 2003). This definition is expanded from the 1975 version of Soil Taxonomy to include soils in areas of Antarctica where pedogenesis occurs but where the climate is too harsh to support the higher plant forms. Soil cover is also considered as a three-dimensional body, the area of which is predetermined by the total area of soils within a territory, and the vertical dimension by the thickness of the soils.

Hence, soil can be considered as the largest pool of terrestrial organic carbon in the biosphere, storing more C than is contained in plants and the atmosphere combined (Schlesinger 1997 in Jobbagy *et al*., 2000). This means that the soil plays a role in contributing carbon on earth. Recently, the role of soil C storage for the global C budget have come to be regarded as equally important. The availability of soil database information is one of the important data to required to support the achievement of mitigation the global greenhouse effect. The detailed data on parameters required for calculating soil carbon stock can be collected through soil mapping research.

Indonesian soil data collection and mapping has been carried out since around 106 years ago. However, a digital soil database management (SDBM) system of ICALRD was just started around the 80's. Since then, a large number of digital data in spatial, tabular and metadata formats have been collected and generated. The large number of soil data can be utilized to estimate soil carbon, which is one factor that plays a role in the global reduction of greenhouse effect. Database of carbon from various land use is required as a basis for determining historical and initial of C stock, C gains (sequestration), or C losses (emission). The data and information are needed to build a system of monitoring the dynamics / changes in carbon stocks needed on various types of soil and land use.

In this paper we will try to relate some parameters stored in Indonesian soil database for estimating soil carbon stock. This paper presents the conditions of Indonesian soil database, utilization soil database for estimating soil carbon, and the result of estimation soil carbon in Indonesia.

2. Indonesian Soil Database

ICALRD provides national leadership of the Indonesian soil survey program and the development and implementation of the national land resources inventory. These two major data collection activities produce valuable natural resources and conservation information on local to national scales for a wide variety of user groups ranging from agricultural producers to decision maker at state level. Since its establishment in 1905, soil data has been collected every year to meet the needs of data and information on Indonesian soil. Until now, soil identification and mapping in Indonesia has covered about 72% of the whole land area at the 1:250.000 scale, about 21% at scale of 1:25,000 to 50,000 and 2.5% at higher scales. But about 10% of the soil inventory and mapping data based on surveys earlier than 1988 have not been digitized yet (Shofiyati and Las, 2010). The coverage of Indonesian soil data collection is displayed in Fig. 1.1. and the status of completion is presented in Table 1.

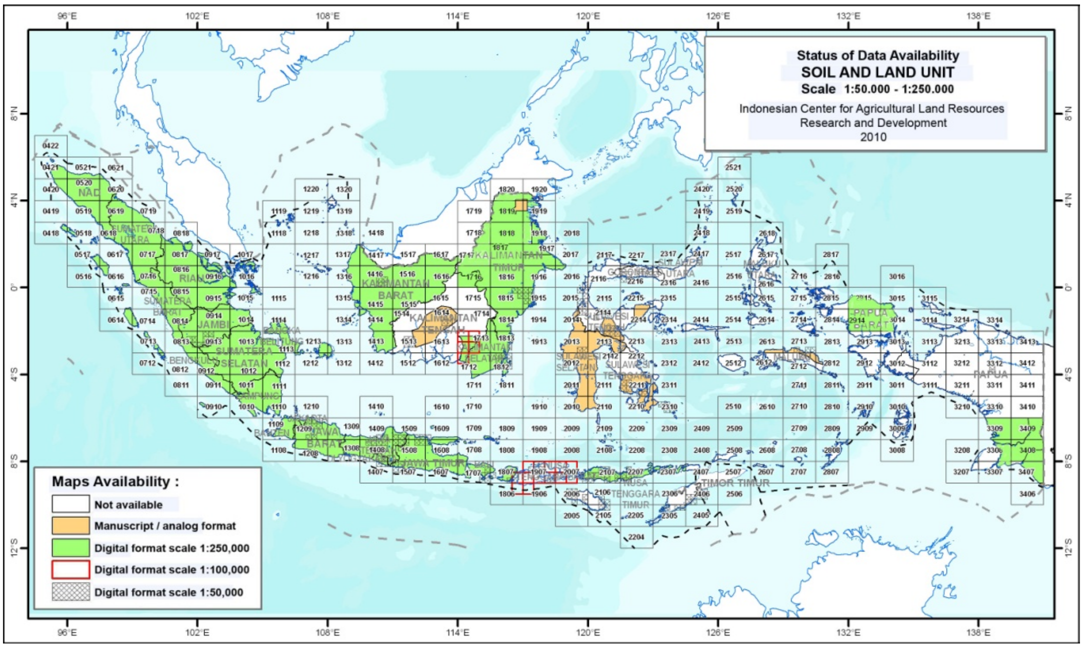

Figure 1. Status of Soil / Land Unit Mapping of Indonesia in 2010

Table 1. Status of Indonesian Soil / Land Mapping Completion

Level of Mapping	Scales	Status (%)
Exploration	1:500,000 – 1:1,000,000	100
Reconnaissance	1:250,000	72
	1:100,000	12
Semi Detail	1:25,000 – 1:50,000	21
Detail	>1:25,000	2.5

Hikmatullah and Hidayat (2007) reported that began the year 1950s, the soil classification used is Dudal and Soepraptohardjo, the National Soil Classification System of Indonesia. Around year 1981 onward, Soil Classification used in Indonesian soil mapping. Digital soil database management (SDBM) system has been carried out in ICALRD since 1988 during Land Resources Evaluation Project I (LREP-I). In the begining of 1990s, some application softwares have been developed to manage such a large amount of data, i.e. Site and Horizon (SHDE4), Soil Sample Analysis (SSA), and Land Unit (LU) in DBF file, except Site and Horizon is in Data Ease formats. Henceforth, the SSA can be integrated with SHDE4, and LU data, and used it in the process of Soil Data Preparation for Land Evaluation (SDPLE), including soil carbon stock estimation. Figure 2. shows flowchart of the soil database management system of ICALRD.

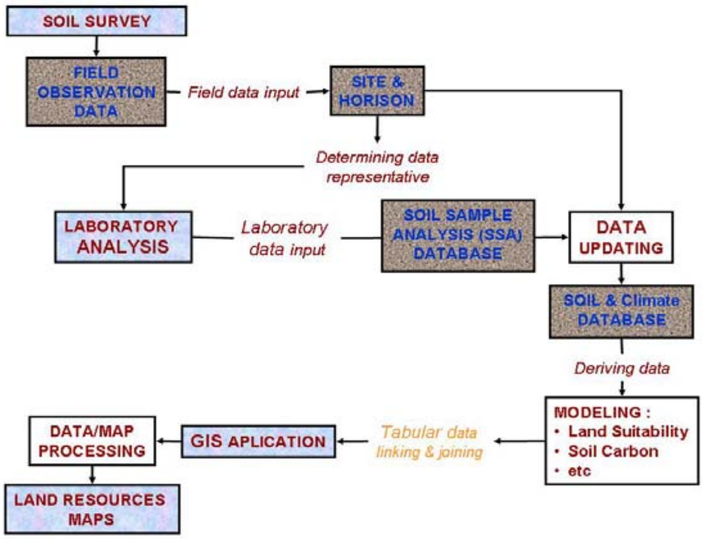

Figure 2. Flowchart of ICALRD Soil Database Management System

The database was designed for multi scales mapping. There are two different versions of database on LREP I (at scale 1:250,000) and LREP II (at scale 1:50,000) in the coding, but basically they have the same contents. Post LREP database using LREP II database version for mapping at a scale 1:250.000. The database contains soil physics and chemical data at each soil horizon to effective soil depth, climate, land surface conditions, and other parameters required for soil classification.

The database also provides a complete form of soil data. But not all data input is stored in the database. Fields that are available on the SSA consists of five things, namely (1) Chemical, (2) Physic, (3) Mineral, (4) X-Ray, and (5) Total soil element (Buurman, 1990; and CSAR, 1994). It has several improvements from the previous version of 1.0 to 2.1. While, Site and Horizon (SHDE4) as a computerized database of land that is specifically designed to store and retrieve pedon data from soil survey activities (Pawitan *et al.*, 1990; Wood-Sichra, 1990; and Wood-Sichra, 1995). SHDE4 version 3.0 used today is the site database that use DataEase and is an enhancement of version 2.5 (Wood-Sichra, 1995). It stores information at various levels of scale of landunit maps, namely: (1) Descriptions of the site and horizon, (2) Reference soil series description, (3) Mapping unit description,

(4) Montly climatic data records, and (5) Polygon attribute information. Polygon attribute data is used as the key to link the tabular database with spatial data (Hof *et al.*, 1998, and Sukardi *et al*., 1996).

Both databases are designed for soil / land mapping. It can also be developed for wider purposes. The field of soil parameters provides in this database can be utilized to support the estimation of soil carbon storage, and have potential to generate other factors related to carbon trading, such as C gains (sequestration), or C losses (emission). Estimation of soil Carbon stock or other factor related to soil orgnic carbon pool use Reference Soil Series (RSS) and SDLPE (Site Data Processing for Land Evaluation) application. RSS application is used to extract data to files, namely RSS_SITE and RSS_HORFORM. While SDPLE application is for land evaluation modelling, as well as for estimating Carbon stock and other carbon pool factors.

The parameters required for calculating soil carbon stock, such as soil organic carbon (C_{org}), and soil bulk density (BD) data are also stored in the database. But only less than 10% of the surveys included bulk density data. Soil Carbon is given in units of mostly soil organic matter content, % C. Digital soil database is only available for map on reconnaissance and semi-detailed level. However, on map at the level of exploration and detail map-scale, detailed digital database information is not available.

3. Carbon Stock Estimation

For purpose of estimating soil carbon stock, the soil data were directly derived from soil data observation of LREP databases. As data for the study, the soils database of LREP I (1989 to 1991), LREP II (1994/95), and Post LREP (2007 to 2009) of ICALRD, and several published and unpublished databases provided by individual researchers have been analyzed. The main data used is LREP I data. A specific reason for analyzing data from LREP I is that an analysis can be made with more complete and consistent soil data than others. Here we focus on analyzing for estimating soil carbon stock in 0-30 cm depth by using available soil database.

Data on soil database that can be extraced for calculating the carbon stock, such as (1) Soil organic carbon determined by wet chemical method or dry combustion and analysis of total carbon. C is in % of mineral soil; and (2) Bulk Density (BD) is determined on ring samples, not on clouds or peds. It is analyzed as BD of oven dry soil (g cm^{-3}). Bulk density data are not always available from soil survey data. Because bulk density was rarely measured, we predicted it using assumptions based on soil type. Referred to Agus *et al.* (2006), bulk density (BD) of mineral soil ranged from 0.6 – 1.4 g cm^{-3}. Andisols have a low soil BD (0.6 – 0.9 g cm^{-3}), whereas BD other soil minerals between 0.8 – 1.4 g cm^{-3}. Peat has a low BD (0.4 – 0.6 g cm^{-3}). Van Noordwijk *et al.* (1997) reported that BD of Histosols is 0.1 – 0.8 Mg m^{-3}, aquic/fluvic (suborders) 1.1 – 1.3 Mg m^{-3}, Andisols 0.65-0.85 Mg m^{-3}, Inceptisols 1.0-1.4 Mg m^{-3}, Oxisols and Ultisols 1.1-1.3 Mg m^{-3}. The lack of BD data can also be utilized by using pedotransfer function (Temple *et al.*, 1996, and Adams, 1973), or Spline method for estimating BD missing data over layer (McKenzie and Ryan, 1999). Some variables needed to calculate mineral soil BD using pedotransfer function are the mean depth of the sample (cm), sand is the percentage by mass of sand (50-2000 μm) (g 100 g^{-1}), and organic matter bulk density = 0.224 g cm^{-3} (Temple *et al.*, 1996). Bulk density is then predicted from mineral bulk density adjusted for organic matter content, calculated using the model of Adams (1973). All of those necessary data is available on soil database ICALRD.

Soil carbon stock was estimated from C_{wet} of soil stored in the Soil Sample Analysis (SSA) related to Site and Horizon (SHDE4) database. C data is given in units of mostly soil organic matter content or % C. Knowing C stock per unit volume of soil bulk density data required. Bulk density of the topsoil for the various groups according to soil data of LREP. Soil carbon stock was estimated by the following formula :

C_{Stock} = BD x C_{org} x D x A ……………………………………………………………….… (1)

Where: C_{Stock} is Soil carbon stock (Mg ha^{-1}), BD is Soil's Bulk Density (g cm^{-3}), directly convertible to Mg m^{-3}), C_{org} is soil organic C content in mass percentage, weight fraction, usually derived from % by weight (g 100 g^{-1}), D is thickness of the soil (m), and A is Area (ha).

Some formula for calculating soil organic carbon as listed below:

Soil organic C content (g kg^{-1}) = C (% weight) * 10 ……………………………………..… (2)

We can also used equation (3). This equation is only required when there is soil organic matter data.

C_{org} (% weight) = % organic matter / 1.724 ……………………………………..………….. (3)

C_{Stock} (kg dm^{-3}) = C (g kg^{-1}) * BD (kg dm^{-3}) = C (0.001 kg g^{-1} * g kg^{-1}) * BD (kg dm^{-3}) …...… (4)

The areas of individual soil groups were directly derived from the Landunit map attribute table that provides the total area of each map unit and area for all taxon components within each map unit. Compilation and linkage of site-specific soil database to soil / land units map provide an estimation of soil carbon stocks in depth of 0 – 30 cm in a particular area. To meet a more accurate results, data was analyzed based on soil great group, while the presentation can be grouped into soil orders.

4. Soil Carbon in Indonesia

Sumatra soil data

As a study, database of Sumatera was used and analysis has been done for South Sumatra Province. The results shows that soil orders found in South Sumatra Province are Inceptisols, Entisols, Ultisols, Oxisols, Histosols, Mollisols, and Andisols. Soil classification system used in LREP I is USDA Soil Taxonomy year 1975. Andisols is presented as andic, therefore a further group of soils with similar properties with Dystrandepts is Hapludands (Uehara and Ikawa H, 2000; Parfitt and Clayden, 1991, Dahlgren *et al.*, 2004). Data required for estimating Soil Carbon stock derived from Sumatra database (LREP I) shown in Table 2.

Table 2. Soil bulk density, organic carbon and carbon stock in one meter depth in each soil order in Sumatra derived from the legacy data.

Soil Order	Bulk Density (Mg m^{-3})		Soil Organic Carbon (% weight)		Soil Carbon Stock (Mg ha^{-1})	
	Average	Range	Average	Range	Average	Range
Alfisols	1.23 ± 0.08	1.07 – 1.31**)	1.43 ± 0.73	0.35 - 2.69	42.31 ± 20.13	10.64 - 75.62
Entisols	1.18 ± 0.24	0.94 – 1.60**)	3.18 ± 2.45	0.04 - 9.91	118.02 ± 97.35	1.25 - 440.04
Histosols	0.44 + 0.04	0.1 – 0.8*)	42.08 ± 10.23	25.10 - 60.18	599.69 ± 143.26	199.52 - 863.91
Inceptisols	1.16 ± 0.16	0.91 - 1.36	2.34 ± 1.57	0.09 - 9.84	70.42 ± 47.74	2.90 - 319.40
Andept (Andisols)	0.80 ± 0.05	0.76 - 0.85 0.65 – 0.85*)	5.24 ± 4.17	0.31 - 19.94	167.64 ± 144.10	7.86 - 855.86
Mollisols	1.34 ± 0.10	1.27 – 1.49**)	3.28 ± 1.75	0.89 - 6.05	99.12 ± 65.92	29.88 - 269.84
Oxisols	1.04 ± 0.18	0.73 - 1.26	2.06 ± 1.15	0.58 - 8.18	61.86 ± 33.84	18.17 - 239.25
Spodosols	0.97 ± 0.17	0.85 - 1.09	3.16 ± 2.54	0.65 -10.39	84.78 ± 85.87	16.11 - 328.59
Ultisols	1.16 ± 0.11	1.00 – 1.31	1.86 ± 1.38	0.15 - 9.87	61.30 ± 44.77	2.18 - 376.31

Sources : *) van Noordwijk *et al.* (1997), Wright and Hanlon (2009), FAO (2001); and **) Suprayogo *et al.* (2006), Seguel and Horn (2006)

Map presented in Figure 3 describes soil carbon stock of 0 – 30 cm depth distribution of South Sumatra Province. Estimation results of soil carbon stock is about 1.2 Gt for South Sumatra Province.

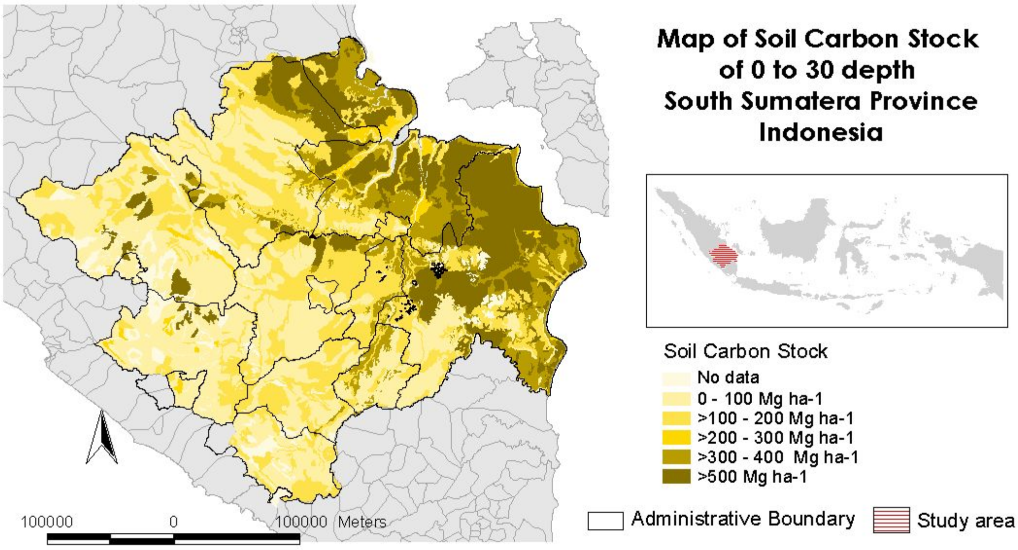

Figure 3. Soil carbon stock (Mg ha^{-1}) of 0 to 30 cm depth of South Sumatra Province, Indonesia

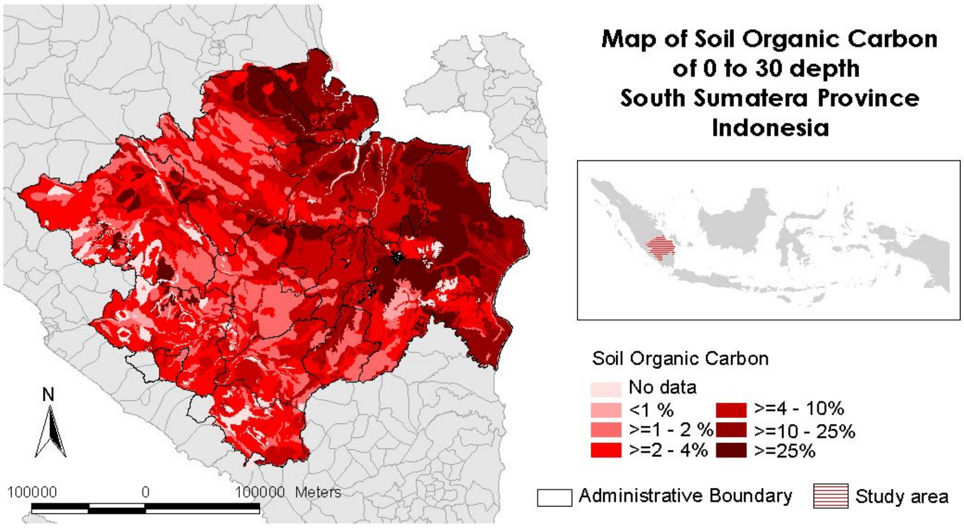

Figure 4. Soil organic carbon (% weight) of 0 to 30 cm depth of South Sumatra Province, Indonesia

Soil Carbon Stock of Indonesia

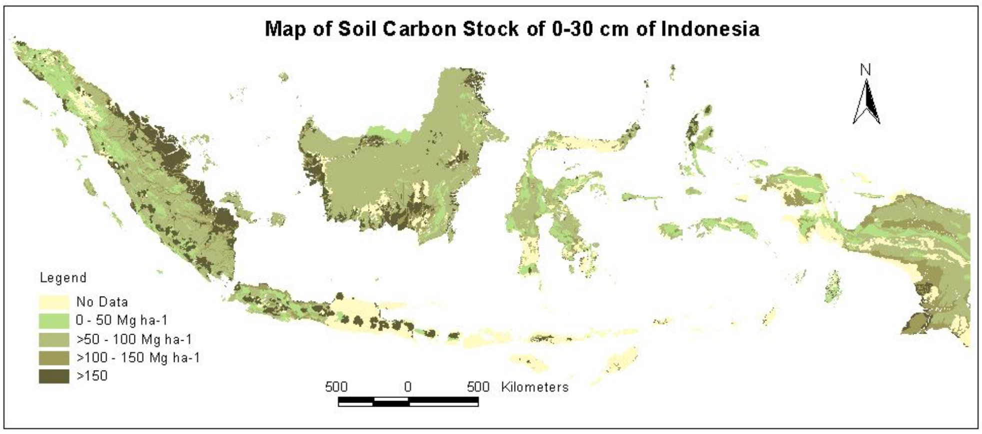

Figure 5. Soil carbon stock (Mg ha^{-1}) of 0 to 30 depth of Indonesia

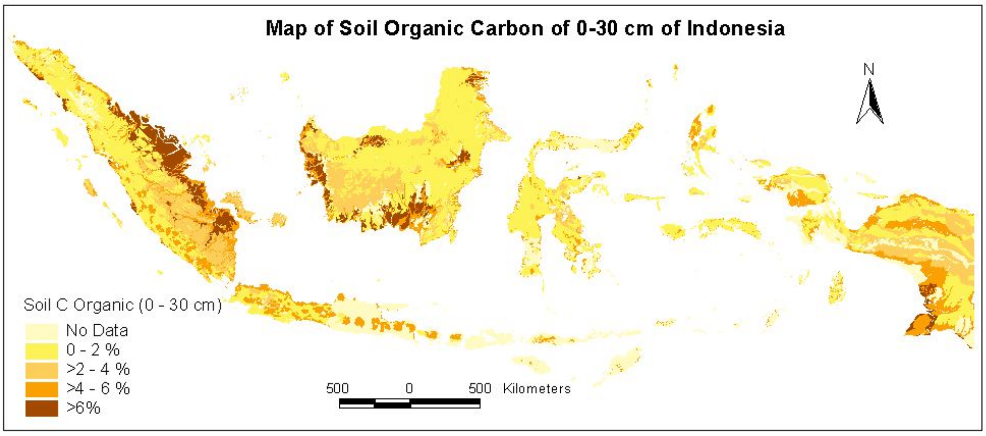

Figure 6. Soil organic carbon (% weight) of 0 to 30 cm depth of Indonesia.

Figure 7 presents the result of C stock estimation of depth 0 – 30 cm of Indonesia based on soil order. Lack of data cause about 18.1% of land can not be calculated for its C stock. They consist of Spodosols and Vertisols, unclassified land or island and ex-mining area.

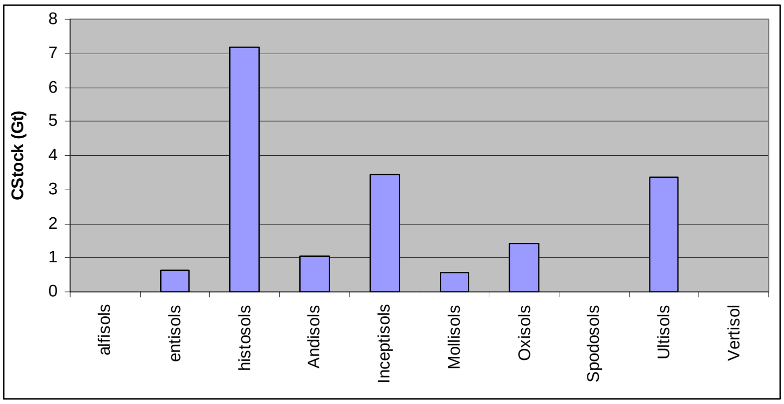

Figure 7. The C stock estimation of depth 0 – 30 cm of Indonesia

Land use types

Each soil group does not only contain landuse types, such as forest, bush, grassland, shifting cultivation, upland, and wetland rice, but also types of vegetation. One mapping unit may contain more than one land use types. However, the current data set does not specify the land use type where the soil pit was taken. Table 3 shows land use type in each land unit of South Sumatra Province. The description of vegetation type is presented in Table 4. The land use data contained in the soil database can not provide information on dominant land use type that can affect the carbon stock. This limits our analysis in relating the change in land use and soil organic carbon content. Future exercise will be to go back to the original database and consult each surveyor about the origin of pit observation.

Table 3. Soil great group and its soil organic content in various of land use type in South Sumatera Province

Soil Group	Landuse					
	Wetland rice	Upland	Shiftcult	Grassland	Bush	Forest
Dystrandepts		*stc*	*l*			
Dystropepts		*stc*	*l*	*a*	*u*	*hz*
Eutrandepts	*s*	*st*	*l*	*at*	*u*	*m*
Eutropepts	*ri*	*tc*		*ta*	*u*	*hzx*
Fluvaquents	*rsi*			*arr*	*u*	*s*
Halpaquepts				*r*		*r*
Haplaquents	*ps*			*r*		*w*
Haplohumults		*c*	*l*		*u*	
hapludolls		*tc*		*a*	*u*	
Haploperox		*tc*	*l*		*u*	*z*
Hapludalfs	*ri*	*t*		*a*	*u*	
Hapludolls		*tc*		*a*	*u*	
Hapludox	*sri*	*tcs*	*l*	*a*	*u*	*zfxhw*
Hapludults	*s*	*tcs*	*l*	*sta*	*u*	*hzdw*
Humitropepts	*ri*	*tc*	*l*	*a*	*u*	*hfz*
Hydrandepts	*ris*	*cts*	*l*	*a*	*u*	*hz*
Hydraquents	*ripl*			*r*	*u*	*nvrto*
Kandiudox			*tc*		*u*	
Kandiudults	*sri*	*tc*	*l*	*a*	*u*	*hzdw*
Kanhapludults	*ri*	*tcs*	*l*	*a*	*u*	*dhz*
Paleudults	*r*	*ct*	*l*		*u*	*hz*
Quartzipsamments					*u*	*o*
Rendolls		*tc*			*u*	
Sulfaquents	*lp*			*r*	*u*	*nrvo*
Sulfihemists		*t*		*r*	*u*	*girw*
Tropaquents	*rs*			*r*	*u*	
Tropaquepts	*rsipl*	*tc*	*l*	*a*	*u*	*hwrzsox*
Tropofluvents	*i*	*c*		*r*	*u*	*s*
Tropohemists	*plsi*			*r*	*u*	*grzqx*
Tropohumods	*r*	*ct*	*l*		*u*	*z*
Tropopsamments	*ir*	*c*		*a*	*u*	*trz*
Troporthents				*a*	*u*	*hfz*
Troposaprists	*plsi*	*t*	*l*	*r*	*u*	*grz*
Vitrandepts		*t*		*t*	*u*	

Soil organic Carbon at 0 - 30cm

- 0 - 2 %
- >2 - 4 %
- >4 - 6 %
- >6%

Table 4. The description of vegetation type is presented in Table 3.

No.	Landuse Type	Descriptions	
1.	Forest	d - dry deciduous forest; f - moist primary sub montane forest; g - peat swamp forest; h - moist primary lowland forest; m - moist primary montane forest; o - gelam forest; q - other forests;	s - swamp forest; r - riparian forest of meander belt; t - tidal forest; v - mangrove forest; w - lowland wetland forest; x - logged forest; z - secondary forest.
2.	Bush and Schrub	u - Bush and Schrub	
3.	Grassland	a - alang-alang (Imperata grass); r – swamp; s – savanna.	
4.	shifting cultivation	l - shifting cultivation	
5.	Upland agriculture	t - grazing land; l - shifting cultivation; c - mixed gardens of fruit trees;	s - horticultural crops; t - upland crops.
6.	Wetland rice	s - wetland rice; i - irrigated wetland rice; l - deepwater rice;	p - tidal wetland rice; r - rainfed wetland rice.

5. Conclusion and Recommendations

- Utilization of soil database will be very prospective in the future in support of improving land management system for carbon sequestration in the soil.
- The results of this analysis demonstrate that Indonesian soil database have a good potential for estimating soil carbon stock, and to generate other factors related to soil carbon pool, as well as to predict soil C losses and sequestration as affected by land use changes and land management systems.
- Bulk density measurement has not been consistently included in the current Indonesian soil survey protocol and this limits our certainty in soil carbon stock and soil emission and sequestration estimates. Since this parameter is critical for carbon stock evaluation, future soil surveys are strongly recommended to include bulk density measurement.
- Integration with other databases, such as climate data base into Land resource database will be is very useful for improved analysis of soil carbon estimation.

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