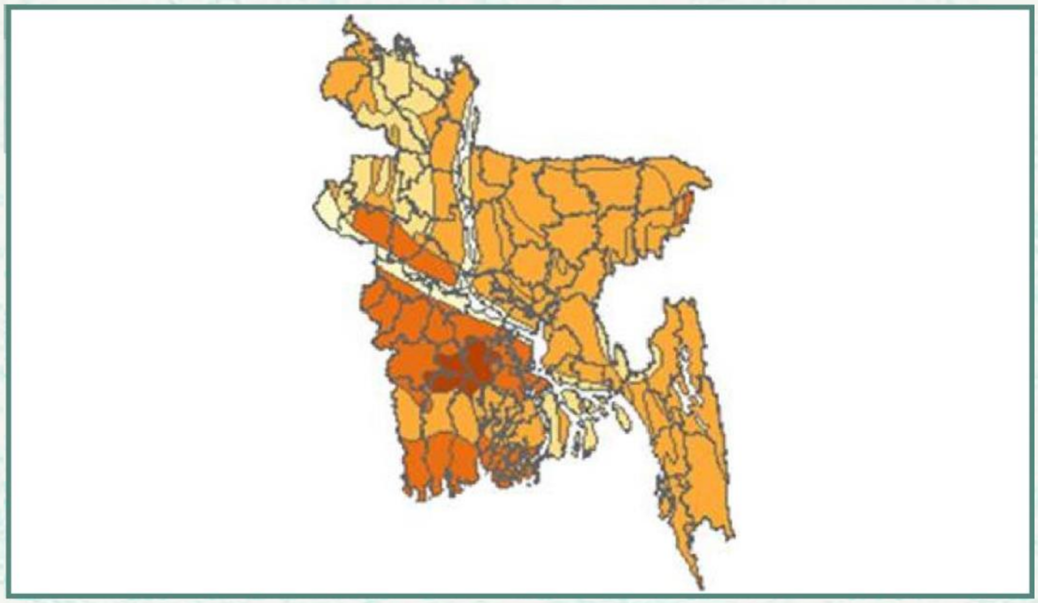
Mapping the soil carbon stocks of Bangladesh



Bangladesh Forest Department

October 2016

UN-REDD PROGRAMME

Food and Agriculture Organization of the United Nations

UN environment

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The application of UNDP, UNEP and FAO rights-based and participatory approaches will also help ensure the rights of indigenous and forest-dwelling people are protected and the active involvement of local communities and relevant stakeholders and institutions in the design and implementation of REDD plans.

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Contents

Executive summary

Soil organic carbon is considered a key indicator of soil quality and productivity and is critical for climate change mitigation and food security especially in a country like Bangladesh where the decline in soil organic matter and soil degradation are considered common problems for the sustainable development of the agriculture sector.

The aim of this report is i) to assess and compare the SOC estimates derived from different digital maps and classification systems and; ii) to assess the SOC stocks of Bangladesh for the different soil and vegetation types, divisions and districts. Two different digital maps were used to represent the soil spatial distribution: a) The Harmonized World Soil Database (HWSD) and b) the soil map entitled "Bangladesh General Soil Type" developed by FAO-UNDP in 1988. Physical and chemical soil properties were derived from the HWSD database which provides data for the topsoil (0-30 cm) and subsoil (30-100 cm) separately.

When comparing the SOC stocks of the HWSD and FAO-UNDP soil map, it appeared that SOC estimates ranged 509.59-640.55 kg C/m^2 in the 0-100 cm soil layer. High variation of SOC stocks was also observed among the different soil types of each soil map. In the HWSD soil map, the variation of SOC among the different soil types ranged between 4.32-422.92 kg C/m^2 in the 0-100 cm. On the other hand, the variation of SOC among the soil types of the FAO-UNDP map ranged between 6.53-124.8 92 kg C/m^2.

Based on the available data used in this study, the highest variability was also observed in the village zone that covers approximately 75% of the national territory and found to have six different soil types. This is also the zone with the highest diversity in terms of land uses as observed from the data analysis using the the GlobCover Land Cover Map 2010.

However, there are several sources of uncertainties in the estimation of SOC stocks due to reliance on old maps, limited data and sampling design. The present study was based on global data with variable reliability given that the number of available soil data was unequal among soil types, districts and zones. The combination of global data with country specific data will allow more accurate estimates. This is important for improved understanding of the SOC pool to assess the potential sequestration for climate change mitigation and food security as well as to identify the most suitable land use management practices for the most vulnerable soils of the country.

1. Introduction

Carbon (C) stored in soils is approximately 3 times greater than the amount of C stored in the atmosphere and 4 times greater that the C stored in biomass (Lal 2004). The soil organic carbon (SOC) represents the two thirds of the global soil C (Batjes 1996). The global soil C pool has been estimated to be approximately 1,500 pentagrams of C (Pg C) but there is great variation across different studies (504–3,000 Pg C, n=27 studies). This variation is associated with the differences in calculation methods and the sampling of soil profile data (e.g. uneven distribution of soil data among different continents) (Scharlemann, Tanner et al. 2014).

The SOC pool is a dynamic pool which is influenced by the amount of C inputs from the above-ground residues and root biomass and C outputs through decomposition (Lal 2004). Land-use activities and management practices can influence the amount of C stored in soils which may act either as a C source or sink depending on the balance between C inputs and outputs (Lal 2004).

On a global scale, emissions from land use and land cover change is considered to be the second largest source of C emissions (IPCC 2007). It has been estimated that a land-use change from forest to cropland can reduce the amount of SOC by 75 % in the tropical soils (Lal 2004). However, there is a great deal of uncertainty in the estimation of C emissions from land-use change (IPCC 2007). In particular, there are key uncertainties related to the amount of SOC stored in soils worldwide, the spatial distribution of SOC stocks and the C emissions from soils (Lal 2005, Scharlemann, Tanner et al. 2014).

The soil C pool has the potential to sequester C and mitigate climate change. The potential of soil C sequestration on a global scale ranges from 0.4 to 1.2 Gigatonnes (Gt) of C per year (Lal 2003). However, the C sequestration capacity and potential of soils is influenced by different factors such as soil type and texture, climate, management practices, vegetation type and natural and anthropogenic disturbances (Jobbágy and Jackson 2000, Lal 2005). For instance, the sequestration rate of tropical soils is generally lower due to different soil types, soil degradation and decline in soil nutrients (Lal 2004).

The sustainable management of SOC is important not only for mitigating climate change through enhancement of soil C stocks but also for food security (Lal 2004). SOC is also considered to be a key indicator of soil quality and productivity (Doran, Coleman et al. 1994). For instance, a study carried out in alluvial soils in India showed that an increase in SOC by 1 ton led to an increase in wheat yield by 6 kg/ha and maize by 3 kg/ha (Lal 2004)

In Bangladesh, it was estimated that in 2010, the agricultural land, including cropland, forestland, mangrove, river, lake, beel-haor, aquaculture, tea and salt pan, covered 83.53 % (12.17 million ha) of the total land area (Hasan 2013). Cropland occupied 60.04 % (8.75 million ha) of the total agriculture land (Hasan 2013). According to the Seventh Five Year Plan of Bangladesh , the agriculture sector contributes 16.0 % of the national GDP (GED 2015) and 45.10 % of labour force employed in agriculture including forestry and fishing (CPD 2016). Despite the average growth (3% annually) of the agriculture sector, food security remains an issue in Bangladesh due to the increasing demands for food and decreasing natural resources (Bishwajit, Barmon et al. 2014).

The decline in soil organic matter and soil degradation are considered common problems for the sustainable development of the agriculture sector in Bangladesh (Hossain 2001). Specifically, It has been estimated that during the period 1967 – 1995 the mean values of SOC in Bangladesh declined by 16.2 t C/ha (Ali 1997). The average SOC of Bangladesh is between 6 and 10 g/kg but the C sequestration potential through adoption of sustainable management practices was estimated at 1.2-1.8 Tg C/yr (Lal 2004). For instance, the SOC in agricultural fields in Bangladesh was estimated at 7.4 g/kg but it increased to 12.8 g/kg due to reforestation (Lal 2004).

In addition, Bangladesh is considered to be one of the most vulnerable countries to climate change (Ali 1999). The country is experiencing extreme climate events that often result in crop failure which in some cases can be 100 % (Mottaleb, Mohanty et al. 2013). Specifically, in India and Bangladesh, the annual loss in rice production can be more than 4 million tons due to floods (Mottaleb, Mohanty et al. 2013).

Bangladesh has a variety of mineral soils that differ in physiography, topography and hydrology (Ali 1997). In 1963, The Soil Resource Development Institute (SRDI) of Bangladesh in collaboration with FAO carried out the Reconnaissance Soil Survey (RSS), which was completed in 1975. The RSS was based on intensive aerial photo interpretation followed by field soil sampling. The total area covered in the RSS was 11,466,913 ha excluding forests. (Imamul Huq 2012).

During the survey, 465 soil series were identified, described and classified and a physical and chemical analysis of these soils were carried out. The results of the soil analysis were published in 33 RSS reports and the information published in these reports were utilized in making the AEZ map of Bangladesh (FAO-UNDP, 1988). Based on the RSS data, Brammer in 1971 classified the soil of Bangladesh into 20 soil types. During 1986-2001, a semi detailed soil survey of the country was conducted based on the RSS data to publish a user friendly “Land and Soil Resources Utilization Guide” for every Upazilla (sub-district) of the country (Imamul Huq 2012). A map of soil organic matter was also developed by SRDI in 1998 and 2010.

A study carried out by Saha et al. (2014) in Bangladesh showed that the SOC stocks at 0-20 cm soil layer was higher (14.19 -4.67 t/ha) in low land followed by medium high land (8.25 – 4.58 t/ha) and high land (6.46 – 3.39 t/ha) (Saha, Rahman et al. 2014). Another study carried out in Tankawati natural hill forest in Bangladesh assessed that the soil carbon stock of forest was 168.15 t/ha (Ullah and Al-Amin 2012). The potential of C sequestration in tree plantations of Chittagong was estimated to be between 83-113 ton/ha (Miah and Bhuiyan 2004).

In consequence, it is important to assess the SOC stocks of Bangladesh for (1) soil fertility and crop production since SOC is associated with soil fertility, (2) climate change mitigation options since the country is willing to contribute to climate change mitigation through REDD+ (UN-REDD 2012). This study aims to enhance understanding of SOC stocks and investigate the geographical distribution of SOC stocks of Bangladesh.

Specifically the objectives of this study are to:

1. Assess and compare the SOC estimates derived from different digital maps and classification systems and;
2. Assess the SOC stocks of Bangladesh for the different soil and vegetation types, divisions and districts.

2. Methodology

2.1 Data sources

2.1.1 Spatial data

Two different digital maps were used to represent the soil spatial distribution: 1) The Harmonized World Soil Database (HWSD) (FAO/IIASA/ISRIC/ISSCAS/JRC 2008) and 2) the soil map entitled "Bangladesh General Soil Type" (Figure 3) developed by FAO-UNDP in 1988.

The Harmonized World Soil Database (HWSD) consists of a shape file which is linked to an attribute database. The HWSD combines information from 9,607 soil profiles with 16,107 soil mapping units/polygons with a spatial resolution of 30 × 30 arc second (~1 × 1 km). The data presented in the HWSD were derived from four spatially explicit soil databases: the European Soil Database, the soil map of China, regional SOil and TERrain (SOTER) databases for Central and Southern Africa, Latin America and the Caribbean, Central and Eastern Europe, and the FAO-UNESCO Soil Map of the World (FAO/IIASA/ISRIC/ISSCAS/JRC 2008).

As mentioned above, the map of soil types of Bangladesh (FAO-UNDP in 1988) was used to estimate the SOC of the different soil types. The map is based on the soil classification system developed in 1971 by Brammer who classified the soils of Bangladesh into 20 soil types. This classification provides information at a general level of soil characteristics. Each soil type identified in the FAO-UNDP map includes several kinds of soil series developed in more than one kind of parent materials and may include a wide range of chemical and physical properties. The objective of this classification system was to provide an overview of soil conditions of Bangladesh (Banglapedia 2016).

In total, three intersection shape files created with QGIS were used in this study: The HWSD shape file was intersected with:

- The Bangladesh district boundaries;
- The map of soil types of Bangladesh (FAO-UNDP, 1988) and;
- The zoning map which was developed based on the analysis of the distribution of forest types of Bangladesh in different soil types, climate, altitude and salinity types (Akhter, Jalal et al. 2016). The zoning map includes five vegetation types: Coastal plantations, Hill, Sal, Sundarban and Village zones.

A zonal statistic was also carried out between the zoning map and the GlobCover Land Cover Map 2010 in order to investigate which zone from the forest zoning map has the highest diversity in terms of land use.

The FAO-UNESCO (1974) legend was used to aggregate the available soil profile data and to link the soil properties with the soil mapping units on the maps. All the areas of the above maps were calculated based on the Bangladesh Transverse Mercator (BTM) projection system.

2.1.2 Soil data

Physical and chemical soil properties were derived from the HWSD database which provides data for the topsoil (0-30 cm) and subsoil (30-100 cm) separately. The HWSD database has data on 40 variables. The HWSD variables that were considered in this study to calculate the SOC stocks were:

- MU_GLOBAL: A code that links the GIS layer to the attribute database
- SHARE: The share (%) of the soil unit within the mapping unit. The total share of each mapping unit is 100%
- OC : the organic carbon (% weight)
- GRAVEL : The gravel content (% vol)
- SAND : the sand fraction (% weight)
- CLAY : The clay fraction (% weight)
- REF_BULK_DENSITY : The reference bulk density (kg/dm^3)

The soil properties were extracted from the HWSD database and allocated to the intersected maps mentioned above in 2.1.1.

SOC stock estimates were also derived from the IPCC tool which is a software package developed by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2003). The IPCC tool estimates the SOC stocks and changes resulting from land-use change. In this study, the default SOC stocks obtained from the IPCC tool for the different soil types of Bangladesh were compared with the estimated SOC stocks derived from the HWSD soil map of Bangladesh and the map of soil types (FAO-UNDP 1988) using data from the HWSD.

2.2 Calculation of soil carbon stocks

The methodology that was used in this study to calculate the SOC stocks is similar to the one used by (Henry 2009). The soil organic carbon calculation was performed using the following equations:

$$C = V \times (1-Gr) \times Bd \times Cc \qquad (1)$$

Where C is the carbon density (kg m^{-2}), V is the soil volume per square meter (m^3), Gr is the volume of gravel (% vol), Bd is the bulk density (kg/dm^3), and Cc is the carbon content (g C kg^{-1}). The HWSD reports soil data per soil type (soil classes) while the spatial data (polygons) are identified as map units. One map unit can contain different soil types. In order to assess the SOC of one map unit, the SOC estimates was calculated according to the proportion (% SHARE) of the soil unit within the map unit per soil depth.

Therefore, the calculation of C density (kgm^{-2}) for each soil profile results from the soil properties per soil type and the composition of soil type per soil depth. For an individual soil profile with k number of layers, the organic carbon of all the layers is:

$$C_d = \sum_{i=1}^{k} V_i (1 - Gr_i) Bd_i Cc_i \qquad (2)$$

Where C_d is the total amount of organic carbon (kg m^{-2}) of all the layers, V is the soil volume per square meter (m^3) of layer i, Gr is the volume of gravel (m^3) of layer i, B_d is the bulk density (kg dm^{-3}) of layer i, and Cc is the carbon content (g C kg^{-1}) of layer i.

The amount of soil carbon per soil map unit was calculated with the formula:

$$M_{ud} = A \times C_{id} \qquad (3)$$

Where M_{ud} is the total mass of organic carbon (kg of C) held in the upper d cm of the soil, A is the area of map unit (m^2), C_{id} is the carbon density of the soil profile (kg m^{-2})

The data were analyzed with R software (Costello 2016). The following packages were used: maps, mapdata, maptools, rgdal, raster, sp, rgeos, ggplot2 and tmap.

3. Results

3.1 SOC stocks derived from the HWSD soil map and the map of soil types of Bangladesh

The digital soil map units of the HWSD soil map of Bangladesh and the map of soil types (FAO-UNDP 1988) were linked to the soil data obtained from the HWSD to represent the geographical distribution of SOC stocks. In total, nine map units were derived from the intersection of the FAO-UNDP map with the HWSD (Table 1). The total area of these map units was estimated at 13,364,591 ha. In the HWSD soil map of Bangladesh, 28 map units were identified covering an area of 14,441,573.76 ha.

Table 1: The soil database and digital maps used to make the soil carbon maps of Bangladesh.

Map ID	Soil data	Spatial data	Year	Soil classification	Map units for Bangladesh	Total area (ha)
1	HWSD	FAO-UNDP	1988	Brammer, 1971	9	13,364,591
2	HWSD	HWSD	2008	FAO-UNESCO, 1974	28	14,441,574

The total amount of SOC stored in the soil types of the FAO-UNDP map was assessed to be 640.55 C/m^2 in the 0-100 cm soil layer (Table 2). The estimation of SOC stocks was based on 95 soil samples representing the 20 soil types based on Brammer's classification. In the HWSD soil map of Bangladesh, the total amount of SOC in the 0-100 cm was estimated to be 509.59 C/m^2.

Table 2: Total SOC stocks for the 0-100 cm soil layer per soil map based on data from the HWSD.

Map ID	Soil data	Spatial data	Year	Soil classification	SOC stocks (kg/ cm^2)	n
1	HWSD	FAO-UNDP	1988	Brammer, 1971	640.55	95
2	HWSD	HWSD	2008	FAO-UNESCO, 1974	509.59	93

3.2 SOC stocks of the soil types of the FAO-UNDP 1988 soil map

The peat soils of the FAO-UNDP map, were found to store the highest amount of SOC both in the 0-30 cm (36.12 kg C/m^2, SD=50.58, n=3) and 30-100 cm (88.68 kg C/m2, SD=142.85, n=3) (Table 3). The peat soils of the FAO-UNDP map were classified based on FAO-UNESCO 1974 soil classification as Cambisols, Gleysols and Histosols (Table 10). In the peat soils, Cambisols occupied 0.01 % (1,256 ha), Gleysols 0.24 % (32,590 ha) and Histosols 0.59% (78, 750 ha) of the total land area of Bangladesh.

In the 0-30 cm soil layer, the lowest (3.62 kg C/m2, SD=0.13, n= 2) amount of SOC was found in the Brown Mottled Terrace Soils. According to the FAO-UNESCO 1974 soil classification, the Brown Mottled Terrace Soils were classified as Gleysols and Nitosols. In the Brown Mottled Terrace Soils, Gleysols occupied 0.26% (34, 490 ha) and Nitosols 0.05% (6, 873 ha) of the total land area.

In the 30-100 cm soil layer, Grey Valley Soils found to store the lowest (2.83 kg C/m2, n=1) amount of SOC. Grey Valley Soils were classified as Nitosols based on the FAO-UNESCO 1974 soil classification. In the Grey Valley Soils, Nitosols occupied 0.02 % (2,033 ha) of the total land.

Table 3: SOC stocks (kg /m^2) per soil type and layer of the soil map FAO-UNDP 1988.

	SOC (kg/m^2)							
	0-30 cm			**30-100 cm**			**0 – 100 cm**	
Soil Types	**Mean**	**SD**	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**
Acid Basin Clays	5.62	3.26	4	4.92	2.94	4	10.54	6.20
Acid Sulphate Soils	5.34	4.55	4	4.44	3.86	4	9.78	8.38
Black Terrai Soils	7.12	3.46	3	5.92	3.04	3	13.04	6.45
Brown Hill Soils	3.75	3.85	6	3.28	3.41	6	7.03	7.26
Brown Mottled Terrace Soils	3.62	0.13	2	3.03	0.29	2	6.64	0.16
Calcareous Aluvium (non-saline)	18.35	37.36	6	44.43	102.49	6	62.78	139.81
Calcareous Brown Floodplain Soils	19.29	37.02	6	45.23	102.14	6	64.52	139.07
Calcareous Dark Grey Floodplain Soils	17.22	34.23	7	39.40	94.51	7	56.62	128.66
Calcareous Grey Floodplain Soils	21.06	41.10	5	52.43	112.48	5	73.49	153.53
Deep Grey Terrace Soils	6.27	3.30	4	5.15	2.93	4	11.41	6.19
Deep Red-Brown Terrace Soils	4.01	0.69	3	3.49	0.83	3	7.50	1.49
Grey Piedmont Soils	5.62	3.26	4	4.92	2.94	4	10.54	6.20
Grey Valley Soils	3.71	-	1	2.83	-	1	6.53	-
Noncalcareous Aluvium	15.53	32.05	8	34.82	88.45	8	50.36	120.43
Noncalcareous Brown Floodplain Soils	4.98	3.58	6	4.17	3.06	6	9.15	6.62
Noncalcareous Dark Grey Floodplain Soils	15.53	32.05	8	34.82	88.45	8	50.36	120.43
Noncalcareous Grey	14.43	30.16	9	31.38	83.38	9	45.81	113.47

Floodplain Soils (non-saline)								
Peat	36.12	50.58	3	88.68	142.85	3	124.80	193.39
Shallow Grey Terrace Soils	5.89	3.94	3	5.09	3.58	3	10.98	7.51
Shallow Red-Brown Terrace Soils	4.88	2.18	3	3.79	1.33	3	8.67	3.50
Total	218.3		95	422.2		95	640.55	

SD: standard deviation, n: number of soil samples

3.3 SOC stocks of the soil types of the HWSD soil map of Bangladesh

The amount of soil C stored in the different soil types and layers of the HWSD soil map of Bangladesh is reported in table 4. In the HWSD soil map, Histosols were found to store the highest amount of SOC both in the 0-30 cm (113.62kg/m^2) and in 30-100 cm (309.30 kg /m^2). Histosols were found to cover 2.3% (337,127 ha) of the total land area of the country. On the contrary, Solonacks had the lowest amount of SOC both in the 0-30 cm (1.65 kg/m^2) and in the 30-100 cm (2.73 kg/m^2). However, in the 0-100 cm, Lithosols had the lowest (4.32 kg C/m^2) SOC stock.

Table 4: SOC stocks (kg/m^2) per major soil type and layer of the HWSD soil map of Bangladesh

	SOC (kg/m^2)							
	0-30 cm			30-100 cm			0-100 cm	
Soil types	**Mean**	**SD**	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**
Acrisols	3.70	1.02	13	3.43	1.07	13	7.13	2.08
Cambisols	5.78	2.88	12	4.96	2.58	12	10.74	5.44
Fluvisols	4.60	3.23	21	6.16	6.20	21	10.75	8.94
Gleysols	5.86	3.59	30	3.98	0.92	30	9.84	4.49
Histosols	113.62	4.69	5	309.30	13.42	5	422.92	18.07
Lithosol	4.32	-	1	0.00	-	1	4.32	-
Luvisols	3.13	0.30	3	3.19	0.33	3	6.31	0.62
Nitosols	3.18	0.86	3	2.85	0.55	3	6.03	0.31
Phaeozems	7.05	-	1	6.08	-	1	13.13	-
Planosols	4.30	-	1	3.79		1	8.09	-
Regosols	2.90	0.20	2	3.03	0.18	2	5.93	0.02
Solonchaks	1.65	-	1	2.73	-	1	4.38	-
Total	160.09		93	349.5		93	509.59	

SD: standard deviation, n: number of soil samples

3.4 Comparison of defaults SOC stocks with SOC estimates derived from the map of soil types (FAO-UNDP 1988) and the HWSD soil map of Bangladesh

The default reference SOC stocks of Bangladesh, obtained from the IPCC tool were compared with the SOC estimates derived from the digital maps based on data from the HWSD (Table 5).

The results obtained from this comparison shows that in some soil types, the IPCC tool overestimated the SOC stocks of the main soil types found in Bangladesh. For instance, the default SOC stocks in the 0-30 cm of Gleysols soil of Bangladesh was 8.6 kg C/m^2 whereas lower amount of SOC was calculated for the Gleysols soils of the two maps based on the HWSD data.

Table 5: Default reference SOC (kg C/m^2) stocks reported by the IPCC tool for the soil types of Bangladesh for the 0-30 cm and SOC estimates derived from the two soil maps based on data from the HWSD database.

		Default SOC (kg/m^2)		Estimated SOC stock (kg/m^2)			
		IPCC tool		FAO-UNDP		HWSD	
		0-30 cm		0-30 cm		0-30 cm	
Main soil Types	IPCC soil classes	Tropical Moist	Tropical Wet	Mean	n	Mean	n
Acrisols	LAC	4.7	6.0	4.80	10	3.50	10
Arenosol	S	3.9	6.6	5.58	1		
Cambisols	HAC	6.5	4.4	10.44	14	4.23	9
Fluvisols	HAC	-	-	7.40	12	4.60	21
Gleysols	A	8.6	8.6	3.53	19	6.11	24
Histosols	O	-	-	94.38	8	115.91	3
Lithosol	HAC	-	-	-	-	4.32	1
Luvisols	HAC	6.5	4.4	-	-	3.02	2
Nitosols	LAC	4.7	6.0	3.71	13	3.18	3
Phaeozems	HAC	6.5	4.4	-	-	7.05	1
Regosols	HAC	6.5	4.4	-	-	2.90	2
Solonchaks	HAC	-	-	-	-	1.65	1

LAC: Low Activity Clay, HAC: High Activity Clay, O: Organic, A: Aquic, S: Sandy

3.5 SOC stocks per district and division of Bangladesh based on the HWSD soil map of Bangladesh

A large variation of SOC stocks was observed among the districts (Table 9) and divisions (Figure 1) of Bangladesh. In the 0-100 cm, Jessore and Narail districts found to store the highest (198.69 kgC/m^2, SD= 211.12, n=2) amount of SOC. Jessore district was calculated to cover 1,79 % (258,330 ha) of the total land area of Bangladesh and Narail 0.69% (99,500 ha). The estimation of SOC for these two districts was based on two soil samples that were available for each district. These samples were classified as Histosols and Gleysols. In the 0-100 cm, the district with the lowest (0.55 kg C/m^2, SD=2.19, n=16) amount of SOC was found in Jhalokati district which covers 0.51 % (73,814.80 ha) of Bangladesh. The soil samples that were available for this district were classified as Gleysols.

At the division level, the greatest (87.08 kg C/m^2, SD= 112.16, n= 34) amount of SOC in the 0-100 cm soil layer was found in Khulna division covering 15.20% (2,195,061.99 ha) of the total land area of Bangladesh. Khulna division was also found to have the highest (6.14- 347.98 kg C/m^2) variation in SOC in the 0-100 cm. The estimation of SOC for Khulna division was based on 34 soil samples that were classified as Fluvisols, Histosols and Gleysols. In the 0-100 cm, the division with the lowest (7.91 kg C/m^2, SD= 1.0, n= 12) amount of SOC and the smallest variation (6.53 – 9.22 kg C/m^2) was found in Mymensingh. The available soil samples for Mymensingh classified as Acrisols, Gleysols, Nitisol, Fluvisols.

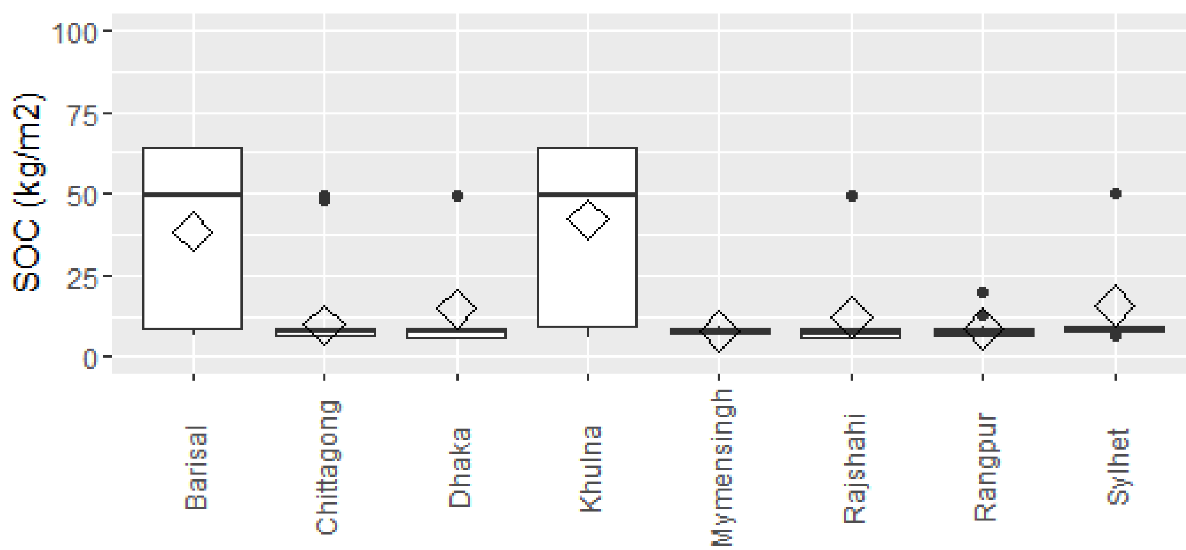

Figure 1: Variability of SOC stocks in the 0-100 cm soil layer among the divisions of Bangladesh.

3.6 SOC stocks per vegetation and soil type based on the HWSD soil map of Bangladesh

In the 0-100 cm soil depth, the zone of Sundarbans found to store the highest (51.82kg C/m^2, SD= 23.92, n=9) amount of SOC. This was followed by Coastal (26.46 kg C/m^2, SD=26.39, n=73), Village (18.31 kg C/m^2, SD= 38.84, n= 193) Hill (15.02 kg C/m^2, SD= 17.04, n= 11), and Sal zone (7.99 kg C/m2, SD= 0.82, n=6).

Table 6: SOC stocks (kg/m^2) per zone and soil depth.

	SOC (kg/m^2)							
	0 -30 cm			30 -100 cm			0 -100 cm	
Zones*	**Mean**	**SD**	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**
Coastal	8.27	6.26	73	18.18	20.34	73	26.46	26.39
Hill	6.20	4.75	11	8.82	12.44	11	15.02	17.04
Village	6.26	7.25	193	12.05	28.38	193	18.31	38.84

Sal	4.53	2.26	6	3.45	0.27	6	7.99	0.82
Sundarbans	14.10	8.03	9	37.73	18.68	9	51.82	23.92

*Proposed zoning for forest monitoring as it was identified by Akhter, Jala et al. (2016).

A high variation of SOC stocks among the different zones and soil layers was also observed in the 0-100 cm (Figure 2). The Village zone found to have the highest (38.84, n=193) variation in SOC in the 0-100 cm while the lowest (SD=0.82, n=6) variation was assessed in Sal zone.

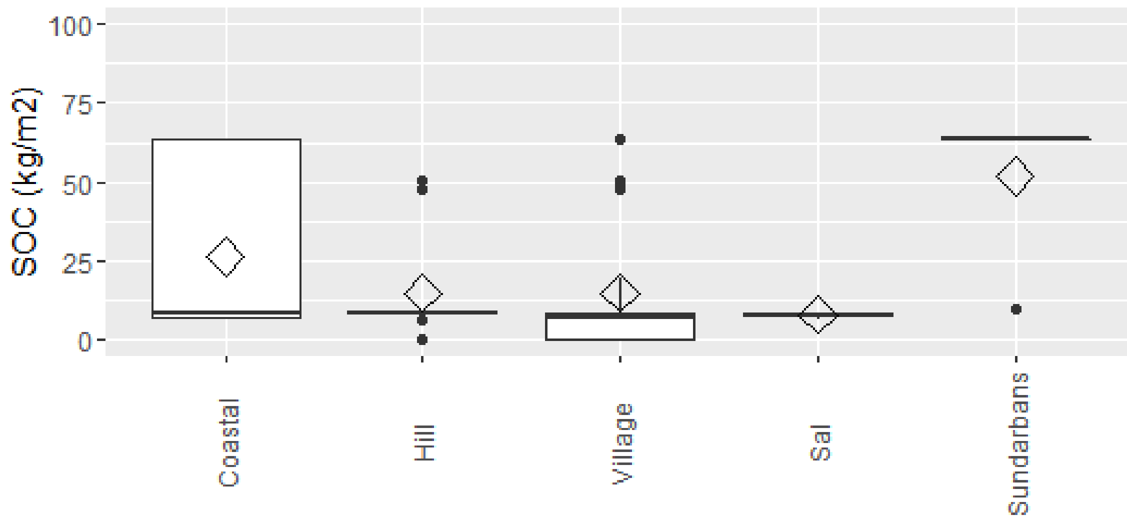

Figure 2: Variation of SOC stocks in the 0-100 cm of the five zones based on the HWSD soil map of Bangladesh.

In the 0-100 cm, the Histosols soils of village zone found to store the highest (347.98 kg C/m2) amount of SOC (Table 7) whereas the lowest (6.72 kg C/m^2) amount of SOC was found in the Acrisols soils of Sal zone. The results also showed that the amount of SOC varied widely among the different soil types that belong to the same zone (e.g. the amount of SOC stored in the hill zone in the 0-100 cm increased from 7.97 kgC/m^2 in Acrisols soils to 8.25 kgC/m^{2}in Cambisols soils). The SOC stock also differed among zones with the same soil type (e.g. in the 0-100 cm, the Fluvisols soils of Sundarbans stored 32.21 kgC/m^2 more C than the Fluvisols soils of coastal zone).

Table 7. SOC stocks per zone, major soil types (FAO-UNESCO 1974 soil classification) and soil depth.

		SOC (kg C/m^2)				
Zones*	**Soil types**	**0-30 cm**	**30-100 cm**	**0-100 cm**	**n**	**Area %**
Coastal	Cambisols	4.84	3.41	8.25	1	0.07
	Fluvisols	9.14	22.53	31.67	53	1.75
	Gleysols	6.04	6.83	12.87	19	0.81

	Not available	0	0	0	44	2.68
	Subtotal	20.02	32.77	52.79	117	5.31
Hill	Acrisols	4.19	3.78	7.97	2	0.42
	Cambisols	4.84	3.41	8.25	2	9.93
	Gleysols	8.36	13.78	22.14	6	0.73
	Not available	0	0	0	7	0.0031
	Subtotal	17.39	20.97	38.36	17	11.08
Sal	Acrisols	3.57	3.15	6.72	1	0.04
	Gleysols	4.63	3.67	8.3	3	0.90
	Nitosols	4.87	3.29	8.16	2	2.77
	Not available	0	0	0	11	0.0035
	Subtotal	13.07	10.11	23.18	17	3.71
Sundarbans	Fluvisols	16.74	47.14	63.88	7	3.08
	Gleysols	4.86	4.78	9.64	2	0.28
	Not available	0	0	0	10	0.36
	Subtotal	21.6	51.92	73.52	19	3.72
Village	Acrisols	3.94	3.58	7.52	3	3.47
	Cambisols	5.43	4.33	9.76	7	3.89
	Fluvisols	4.44	8.00	12.43	50	6.10
	Gleysols	9.47	17.71	27.18	77	42.77
	Histosols	94.38	253.59	347.98	2	2.33
	Nitosols	4.48	3.13	7.62	3	0.54
	Regosols	5.58	3.83	9.41	1	0.03
	Not available	0	0	0	300	15.05
	Subtotal	127.72	294.17	421.9	443	74.18
Water bodies		0	0	0		1.98
Total		199.8	409.94	609.75	1226	100

*Proposed zoning for forest monitoring as it was identified by Akhter, Jala et al. (2016).

4. Discussion

The results presented in this study shows that the total soil carbon stocks of Bangladesh varied widely among the different soil maps, classification systems and soil types. More specifically, based on the data from the HWSD, the total SOC stocks in the 0-100 cm soil layer was found to be lower in the HWSD soil map (509.59 kg C/m^2) of Bangladesh compared to the FAO-UNDP soil map (640.55 kg C/m^2) (Table 2). This difference might be attributed to the fact that the number of soil types was greater (20 soil types) in the FAO-UNDP map compared to the HWSD (12 soil types) soil map of Bangladesh. In addition, in the FAO-UNDP map slightly more map units (94 %) contained soil compared to the HWSD soil map of Bangladesh (93%). Also, the number of soil samples available for the FAO-UNDP map was slightly higher than the soil samples of the HWSD map.

In the 0-100 cm soil layer, large variability of SOC stocks was observed among the soil types of the HWSD map and the FAO-UNDP map. In the 0-100 cm, the SOC varied between 4.32 - 422.92 kg C/m^2 (Table 4) in the HWSD soil map, whereas in the FAO-UNDP map the SOC varied between 6.53 - 124.8 kg C/m^2 (Table 3). In both maps, Histosols (peat soils) which are soils that contain more than 20 % organic matter by weight (Driessen, Deckers et al. 2000) was found to have the highest amount of soil carbon. According to SRDI, Histosols are mainly found in the Gopalganj-Khulna and in the Sunamganj-Netrokona areas and cover 1% of the total land area of Bangladesh (SRDI 1963-1975). However, Histosols estimated to cover 2.3% (337,127 ha) in the HWSD soil map and 2.4% (325,886 ha) in the FAO-UNDP map.

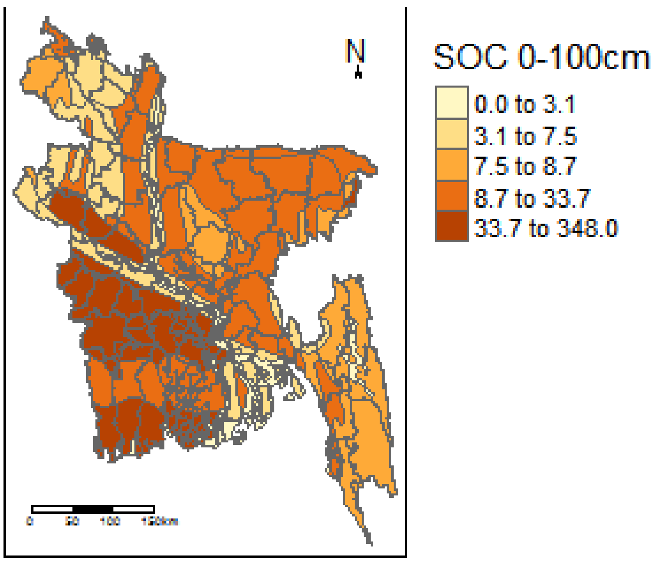

Figure 3: Map of SOC (kg C/m^2) of the HWSD soil map based on data from the HWSD of Bangladesh.

At the district level, the greatest variation (49-348 kg C/m^2) of SOC stocks in the 0-100 cm was observed for Jessore and Narail districts. The high variation of SOC stocks among districts might be attributed to the variety of soil types found among the districts. In total, 14 major soil types were identified in the districts of Bangladesh. In addition, the high variation of SOC stocks among the districts might be associated with the unequal distribution of soil samples. Specifically, a greater number of soil samples were available for the assessment of SOC stocks for Patuakhali district (n= 101) whereas the assessment of SOC stocks for Jessore and Narail districts was based on two soil samples respectively (Table 9). In total, 863 soil samples were available for the 64 districts of Bangladesh.

The amount of carbon stored in soils varied also widely among different zones .In the 0-100 cm, the highest variation (7.52- 347.98 kg C/m^2) of SOC was observed in the village zone (Table 6) that covers approximately 75% of the total land area of Bangladesh. The reason behind this variation could be the number of soil and vegetation types as well as management practices. Specifically, the village zone seemed to have the highest number of soil types than any other zone (Table 7). Moreover, the village zone found to have the highest diversity of land use based on the analysis of the data obtained from the GlobCover Land Cover Map 2010. The analysis showed that 67% of the village zone was classified as cropland, 7% as forestland, 3% as wetland, 0.4% as settlements, 0.3% as other land and 0.02 as grassland.

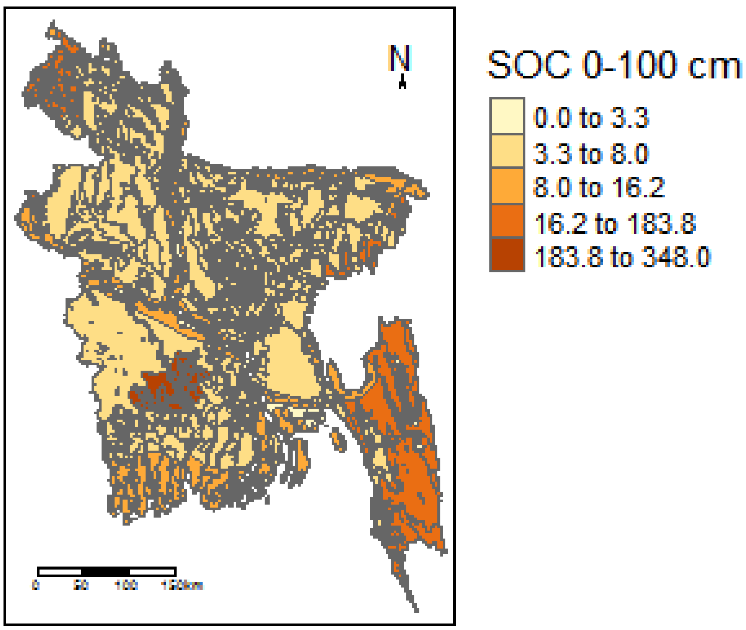

Figure 4: Map of SOC (kg C/m^2) of the FAO-UNDP 1988 soil map based on data from the HWSD of Bangladesh.

The zone of Sundarbans that cover approximately 4% of the total land area of Bangladesh found to store 40% of the total SOC stored in the five zones ranging from 9.64 – 63.88 kg C/m^2 in the 0-100 cm (Table 7). Another study carried out in the Sundarbans forest of Bangladesh showed significant differences of soil carbon among different vegetation types and a high range of SOC (90.03 – 134.17 Mg/ha) (Mizanur Rahman 2015). Specifically, the study revealed that in the fresh water zone, the forests dominated by *Heritiera fomes* had higher soil carbon stocks (196.54 Mg/ha) than any other vegetation type such as forests dominated by *Heritiera fomes-Excoecaria agallocha* (Mizanur Rahman, Nabiul Islam Khan et al. 2015). The study also showed that the amount of carbon stored in soils was similar to the total amount of carbon stored in aboveground biomass among different vegetation types and strong saline zones (Mizanur Rahman 2015).

According to the HWSD soil map, the total soil carbon stocks for the five zones of Bangladesh were 199.8 kgC/m^2 for the 0-30 cm soil depth and 409.94 kgC/m^2 for the 30-100 cm.for the layer and respectively (Table 7). The above assessment is based on 241 soil samples that belong to seven major soil groups and cover approximately 80% of the total land area of Bangladesh. A comparison of the above estimates on SOC stocks with estimates on national SOC stocks from other sources was not possible due to lack of information.

The SOC estimates presented in this study are from the most recent and detailed map of SOC based on the HWSD database (FAO/IIASA/ISRIC/ISSCAS/JRC 2008) and from an old map . However, the accuracy of the SOC stocks estimates might be influenced by different factors: 1) the map relies largely on the spatial resolution FAO soil maps from the 1970s (Scharlemann, Tanner et al. 2014), 2) lack of soil samples and uneven distribution of soil samples across the country, 3) soil samples were available up to 100 cm soil depth, 4) national boundaries need to be refined as they might lead to overestimation of SOC. Therefore, in order to improve the estimates of SOC stocks at the national level data need to be updated considering national specific soil maps and databases.

5. Conclusion

This study presents high variation of SOC stocks of Bangladesh among the different soil maps based on data from the HWSD. When comparing the SOC stocks of the HWSD and FAO-UNDP soil map, it appeared that SOC estimates ranged 509.59-640.55 kg C/m^2 in the 0-100 cm soil layer. High variation of SOC stocks was also observed among the different soil types of each soil map. In the HWSD soil map, the variation of SOC among the different soil types ranged between 4.32-422.92 kg C/m^2 in the 0-100 cm. On the other hand, the variation of SOC among the soil types of the FAO-UNDP map ranged between 6.53-124.8 92 kg C/m^2.

Based on the available data used in this study, the highest variability was also observed in the village zone that covers approximately 75% of the national territory and found to have six different soil types. This is also the zone with the highest diversity in terms of land uses as observed from the data analysis using the the GlobCover Land Cover Map 2010.

However, there are several sources of uncertainties in the estimation of SOC stocks due to reliance on old maps, limited data and sampling design. The present study was based on global data with variable reliability given that the number of available soil data was unequal among soil types, districts and zones. The combination of global data with country specific data will allow more accurate estimates. This is important for improved understanding of the SOC pool to assess the potential sequestration for climate change mitigation and food security as well as to identify the most suitable land use management practices for the most vulnerable soils of the country.

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7. Annexes

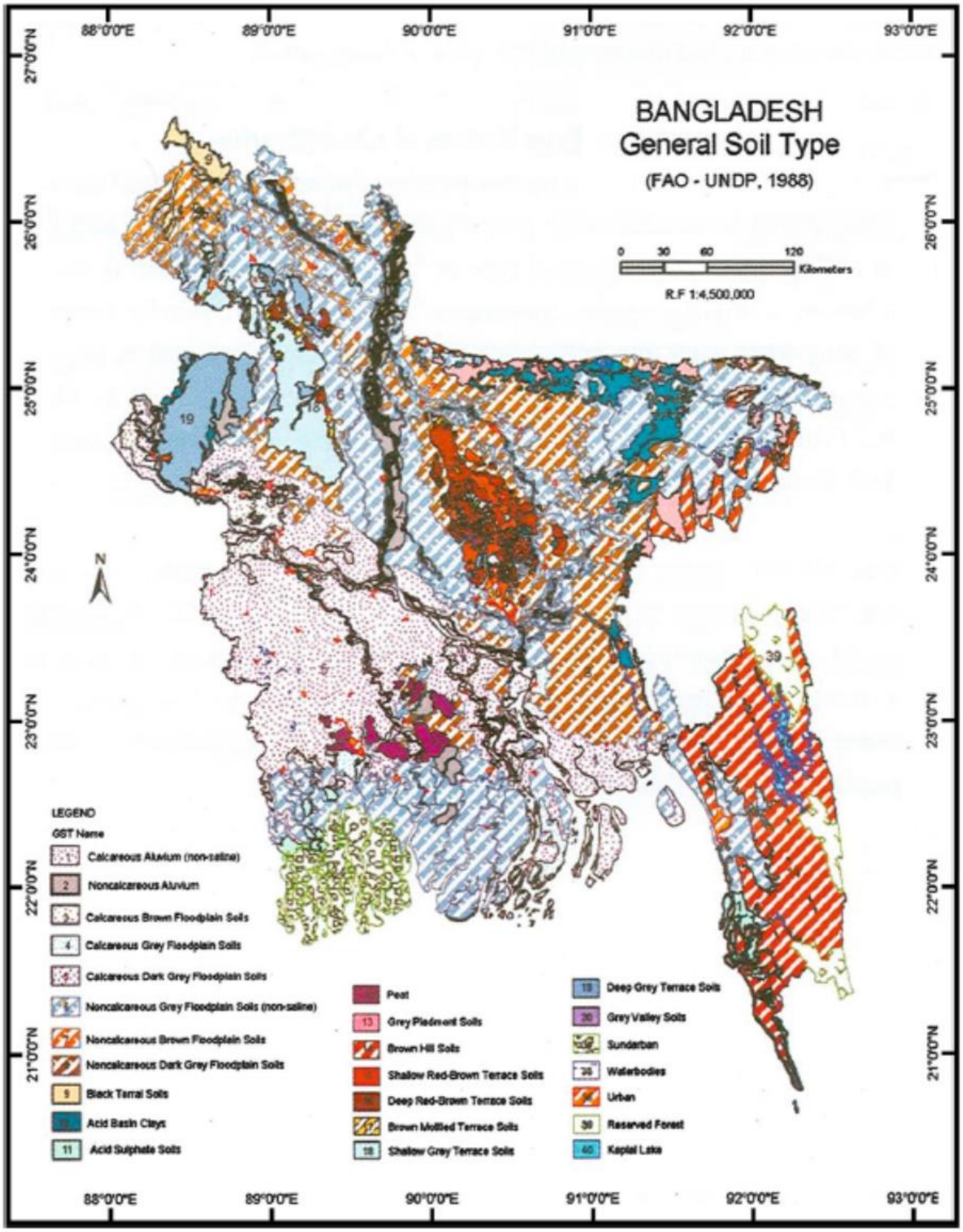

Figure 5. Soil map of Bangladesh developed by FAO-UNDP 1988. The map is based on Brammer's classification.

Table 8. Soil organic carbon stocks (kg/m^2) per soil type for the total soil layer 0-100 cm. SD is the standard deviation and n is the number of soil samples available per soil type.

Soil type	**Mean**	**SD**	**Min.**	**Max.**	**n**
Calcaric Fluvisols	8.40	0.00	8.40	8.40	2
Calcaric Gleysols	8.69	0.80	7.06	9.01	6
Chromic Luvisols	6.52	-	6.52	6.52	1
Dystric Cambisols	9.50	0.00	9.50	9.50	2
Dystric Fluvisols	7.04	0.64	5.46	7.26	8
Dystric Gleysols	8.85	0.00	8.85	8.85	3
Dystric Histosols	430.73	0.00	430.73	430.73	3
Dystric Nitosols	6.21	0.00	6.21	6.21	2
Dystric Regosols	5.92	-	5.92	5.92	1
Eutric Cambisols	7.22	0.00	7.22	7.22	5
Eutric Fluvisols	5.82	0.00	5.82	5.82	7
Eutric Gleysols	7.66	0.65	5.37	8.09	15
Eutric Histosols	390.60	-	390.60	390.60	1
Eutric Nitosols	5.68	-	5.68	5.68	1
Eutric Planosols	8.09	-	8.09	8.09	1
Eutric Regosols	5.94	-	5.94	5.94	1
Ferric Acrisols	5.87	0.34	5.48	6.07	3
Ferric Luvisols	5.61	-	5.61	5.61	1
Gleyic Acrisols	5.69	0.00	5.69	5.69	2
Gleyic Cambisols	7.42	0.00	7.42	7.42	2
Gleyic Solonchaks	4.38	-	4.38	4.38	1
Gleysols	8.85	0.00	8.85	8.85	2
Haplic Phaeozems	13.13	-	13.13	13.13	1
Histosols	431.80	-	431.80	431.80	1
Humic Acrisols	13.57	-	13.57	13.57	1
Humic Cambisols	19.66	0.00	19.66	19.66	3
Humic Gleysols	20.94	0.00	20.94	20.94	4
Lithosols	4.32	-	4.32	4.32	1
Orthic Acrisols	7.34	0.17	7.27	7.68	6
Orthic Luvisols	6.81	-	6.81	6.81	1
Plinthic Acrisols	6.13	-	6.13	6.13	1
Thionic Fluvisols	27.99	6.21	24.89	37.31	4

Table 9: SOC stocks (Kg/m^2) per district of Bangladesh for the total soil layer 0-100 cm based on the HWSD soil map of Bangladesh.

District	Mean	SD	Min.	Max.	n	Area (ha)
Bagerhat	46.64	103.22	0.00	347.98	21.00	396402.54
Bandarban	8.25	NA	8.25	8.25	1.00	459900
Barguna	7.14	20.08	0.00	63.88	37.00	149071.5773
Barisal	22.80	51.74	0.00	347.98	51.00	248935.852
Bhola	20.87	23.69	0.00	63.88	40.00	297457.0103
Bogra	6.01	3.45	0.00	8.78	5.00	291053.8
Brahamanbaria	3.87	4.55	0.00	8.78	4.00	192175.5
Chandpur	1.11	2.89	0.00	8.78	22.00	169795.26
Chapai Nawabganj	7.37	1.24	6.14	8.63	3.00	168540
Chittagong	2.56	3.80	0.00	8.78	31.00	466030.7502
Chuadanga	49.41	NA	49.41	49.41	1.00	116500
Comilla	5.16	4.35	0.00	8.78	20.00	308641.5563
Cox'S Bazar	6.42	12.58	0.00	47.70	27.00	235822.0882
Dhaka	0.86	2.47	0.00	8.78	44.00	147494.5948
Dinajpur	7.87	0.99	6.76	8.78	4.00	346000
Faridpur	38.36	103.68	0.00	347.98	11.00	204228.0569
Feni	5.80	3.38	0.00	8.78	9.00	92993.69
Gaibandha	5.68	3.89	0.00	8.78	4.00	216477
Gazipur	8.47	0.44	8.16	8.78	2.00	181552
Gopalganj	135.39	185.22	8.78	347.98	3.00	147447.3
Habiganj	7.92	1.07	6.72	8.78	3.00	258131
Jamalpur	6.36	3.21	0.00	8.78	6.00	206430.4
Jessore	198.69	211.12	49.41	347.98	2.00	258330
Jhalokati	0.55	2.19	0.00	8.78	16.00	73814.80284
Jhenaidah	49.41	NA	49.41	49.41	1.00	195500
Joypurhat	8.05	1.02	7.33	8.78	2.00	95966
Khagrachhari	4.99	4.39	0.00	8.25	3.00	285593
Khulna	65.86	93.45	0.00	347.98	12.00	415511.9712
Kishoreganj	8.36	0.36	8.16	8.78	3.00	256315
Kurigram	6.37	3.26	0.00	8.78	6.00	226694.39
Kushtia	11.31	18.91	0.00	49.41	6.00	161379.4797
Lakshmipur	10.56	17.64	0.00	49.41	13.00	155745.1237
Lalmonirhat	7.99	1.30	6.76	9.41	4.00	126319.37
Madaripur	10.85	51.14	0.00	347.98	48.00	113435.03
Magura	49.41	NA	49.41	49.41	1.00	104800
Manikganj	0.97	2.48	0.00	8.78	51.00	137325.3903
Maulvibazar	15.55	17.09	8.25	50.43	6.00	267877
Meherpur	49.41	NA	49.41	49.41	1.00	72220
Munshiganj	3.28	4.25	0.00	8.78	34.00	93192.28

Mymensingh	7.82	1.16	6.53	8.78	3.00	434560.7
Naogaon	21.84	23.89	7.33	49.41	3.00	344161
Narail	198.69	211.12	49.41	347.98	2.00	99500
Narayanganj	3.87	4.45	0.00	8.78	18.00	70309.01518
Narsingdi	8.36	0.36	8.16	8.78	3.00	116700
Natore	17.91	21.02	6.14	49.41	4.00	190323
Netrakona	8.18	1.44	6.53	9.22	3.00	280261
Nilphamari	13.21	9.12	6.76	19.66	2.00	158779
Noakhali	4.94	3.31	0.00	8.78	30.00	314537.1778
Pabna	5.98	11.67	0.00	49.41	17.00	238783.98
Panchagarh	11.94	5.71	6.76	19.66	4.00	131530
Patuakhali	11.89	24.41	0.00	63.88	101.00	314739.4939
Pirojpur	24.47	78.10	0.00	347.98	20.00	127164.286
Rajbari	6.16	11.93	0.00	49.41	16.00	113834.2575
Rajshahi	17.91	21.02	6.14	49.41	4.00	243778
Rangamati	4.26	4.92	0.00	8.78	4.00	576640.05
Rangpur	7.62	1.04	6.76	8.78	3.00	234240
Satkhira	26.11	28.57	0.00	63.88	5.00	374918
Shariatpur	12.19	20.44	0.00	49.41	40.00	125094.9823
Sherpur	8.78	NA	8.78	8.78	1.00	132500
Sirajganj	6.01	3.45	0.00	8.78	5.00	249278
Sunamganj	18.74	21.16	6.53	50.43	4.00	369249
Sylhet	19.17	20.84	8.25	50.43	4.00	341895
Tangail	6.50	2.95	0.00	8.78	7.00	336339
Thakurgaon	7.98	0.92	7.33	8.63	2.00	181360

Table 10. SOC stocks of the 20 soil types of the soil map (FAO-UNDP 1988) using data from the HWSD database.

Soil Types FAO-UNDP 1988	Major soil types FAO-UNESCO 1974	SOC stocks (kg C/m^2)				
		0-30 cm	30-100cm	0-100cm	n	Area %
Acid Basin Clays	Acrisols	4.80	4.42	9.22	1	0.44
	Cambisols	10.44	9.22	19.66	1	0.00003
	Gleysols	3.53	3.23	6.76	1	1.91
	Nitosols	3.71	2.83	6.54	1	0.11
Acid Sulphate Soils	Cambisols	10.44	9.22	19.66	1	0.09
	Fluvisols	7.40	5.31	12.71	1	0.13
	Gleysols	3.53	3.23	6.76	1	0.27
	No data	0	0	0	1	0.09
Black Terrai Soils	Cambisols	10.44	9.22	19.66	1	0.47
	Fluvisols	7.40	5.31	12.71	1	0.07
	Gleysols	3.53	3.23	6.76	1	0.01
Brown Hill Soils	Acrisols	4.80	4.42	9.22	1	0.48
	Cambisols	10.44	9.22	19.66	1	7.80
	Gleysols	3.53	3.23	6.76	1	0.93
	Nitosols	3.71	2.83	6.54	1	0.00004
	Water Bodies	0	0	0	1	0.44
	No data	0	0	0	1	0.03
Brown Mottled Terrace Soils	Gleysols	3.53	3.23	6.76	1	0.26
	Nitosols	3.71	2.83	6.54	1	0.05
Calcareous Aluvium (non-saline)	Acrisols	4.80	4.42	9.22	1	0.01
	Fluvisols	7.40	5.31	12.71	1	2.08
	Gleysols	3.53	3.23	6.76	1	0.38
	Histosols	94.38	253.59	347.97	1	0.06
	Water bodies	0	0	0	1	0.10
	No data	0	0	0	1	1.61
Calcareous Brown Floodplain Soils	Cambisols	10.44	9.22	19.66	1	0.04
	Fluvisols	7.40	5.31	12.71	1	0.78
	Gleysols	3.53	3.23	6.76	1	1.23
	Histosols	94.38	253.59	347.97	1	0.10
	Water bodies	0	0	0	1	0.001
	No data	0	0	0	1	0.10
Calcareous Dark Grey Floodplain Soils	Acrisols	4.80	4.42	9.22	1	0.05
	Cambisols	10.44	9.22	19.66	1	0.07

	Fluvisols	7.40	5.31	12.71	1	1.52
	Gleysols	3.53	3.23	6.76	1	11.73
	Histosols	94.38	253.59	347.97	1	1.06
	Water bodies	0	0	0	1	0.09
	No data	0	0	0	1	0.14
Calcareous Grey Floodplain Soils	Fluvisols	7.40	5.31	12.71	1	0.35
	Gleysols	3.53	3.23	6.76	1	0.48
	Histosols	94.38	253.59	347.98	1	0.04
	Water bodies	0	0	0	1	0.01
	No data	0	0	0	1	0.19
Deep Grey Terrace Soils	Cambisols	10.44	9.22	19.66	1	0.00003
	Fluvisols	7.40	5.31	12.71	1	0.16
	Gleysols	3.53	3.23	6.76	1	2.46
	Nitosols	3.71	2.83	6.54	1	0.02
Deep Red-Brown Terrace Soils	Acrisols	4.80	4.42	9.22	1	0.01
	Gleysols	3.53	3.23	6.76	1	0.54
	Nitosols	3.71	2.83	6.54	1	1.52
Grey Piedmont Soils	Acrisols	4.80	4.42	9.22	1	0.39
	Cambisols	10.44	4.42	19.66	1	0.23
	Gleysols	3.53	3.23	6.76	1	0.94
	Nitosols	3.71	2.83	6.54	1	0.01
Grey Valley Soils	Nitosols	3.71	2.83	6.54	1	0.02
Noncalcareous Aluvium	Acrisols	4.80	4.42	9.22	1	0.65
	Cambisols	10.44	9.22	19.66	1	0.06
	Fluvisols	7.40	5.31	12.71	1	0.17
	Gleysols	3.53	3.23	6.76	1	1.58
	Histosols	94.38	253.59	347.98	1	0.13
	Nitosols	3.71	2.83	6.54	1	0.01
	Water bodies	0	0	0	1	0.62
	No data	0	0	0	1	0.12
Noncalcareous Brown Floodplain Soils	Acrisols	4.80	4.42	9.22	1	0.07
	Cambisols	10.44	9.22	19.66	1	1.22
	Fluvisols	7.40	5.31	12.71	1	0.04
	Gleysols	3.53	3.23	6.76	1	1.63
	Nitosols	3.71	2.83	6.54	1	0.01
	Water bodies	0	0	0	1	0.00002
Noncalcareous Dark Grey Floodplain Soils	Acrisols	4.80	4.42	9.22	1	0.27
	Cambisols	10.44	9.22	19.66	1	0.60
	Fluvisols	7.40	5.31	12.71	1	0.33
	Gleysols	3.53	3.23	6.76	1	11.55

	Histosols	94.38	253.59	347.98	1	0.34
	Nitosols	3.71	2.83	6.54	1	0.65
	Water bodies	0	0	0	1	0.004
	No data	0	0	0	1	0.03
Noncalcareous Grey Floodplain Soils (non-saline)	Acrisols	4.80	4.42	9.22	1	1.46
	Cambisols	10.44	9.22	19.66	1	1.41
	Fluvisols	7.40	5.31	12.71	1	2.13
	Gleysols	3.53	3.23	6.76	1	21.22
	Arenosols	5.58	3.83	9.41	1	0.03
	Histosols	94.38	253.59	347.98	1	0.12
	Nitosols	3.71	2.83	6.54	1	0.23
	Water bodies	0	0	0	1	0.19
	No data	0	0	0	1	0.35
Peat	Cambisols	10.44	9.22	19.66	1	0.01
	Gleysols	3.53	3.23	6.76	1	0.24
	Histosols	94.38	253.59	347.98	1	0.59
Shallow Grey Terrace Soils	Cambisols	10.44	9.22	19.66	1	0.08
	Gleysols	3.53	3.23	6.76	1	2.47
	Nitosols	3.71	2.83	6.54	1	0.13
Shallow Red-Brown Terrace Soils	Fluvisols	7.40	5.31	12.71	1	0.005
	Gleysols	3.53	3.23	6.76	1	0.08
	Nitosols	3.71	2.83	6.54	1	0.72