Mapping Haiti Soils by Combining Traditional and Digital Soil Mapping Techniques

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Introduction

Soil is an important natural resource yet for many countries including Haiti the only soil inventory is a general soil map at 1:250,000 scale which is not suitable for management planning at the farm level (**Figure 1**).

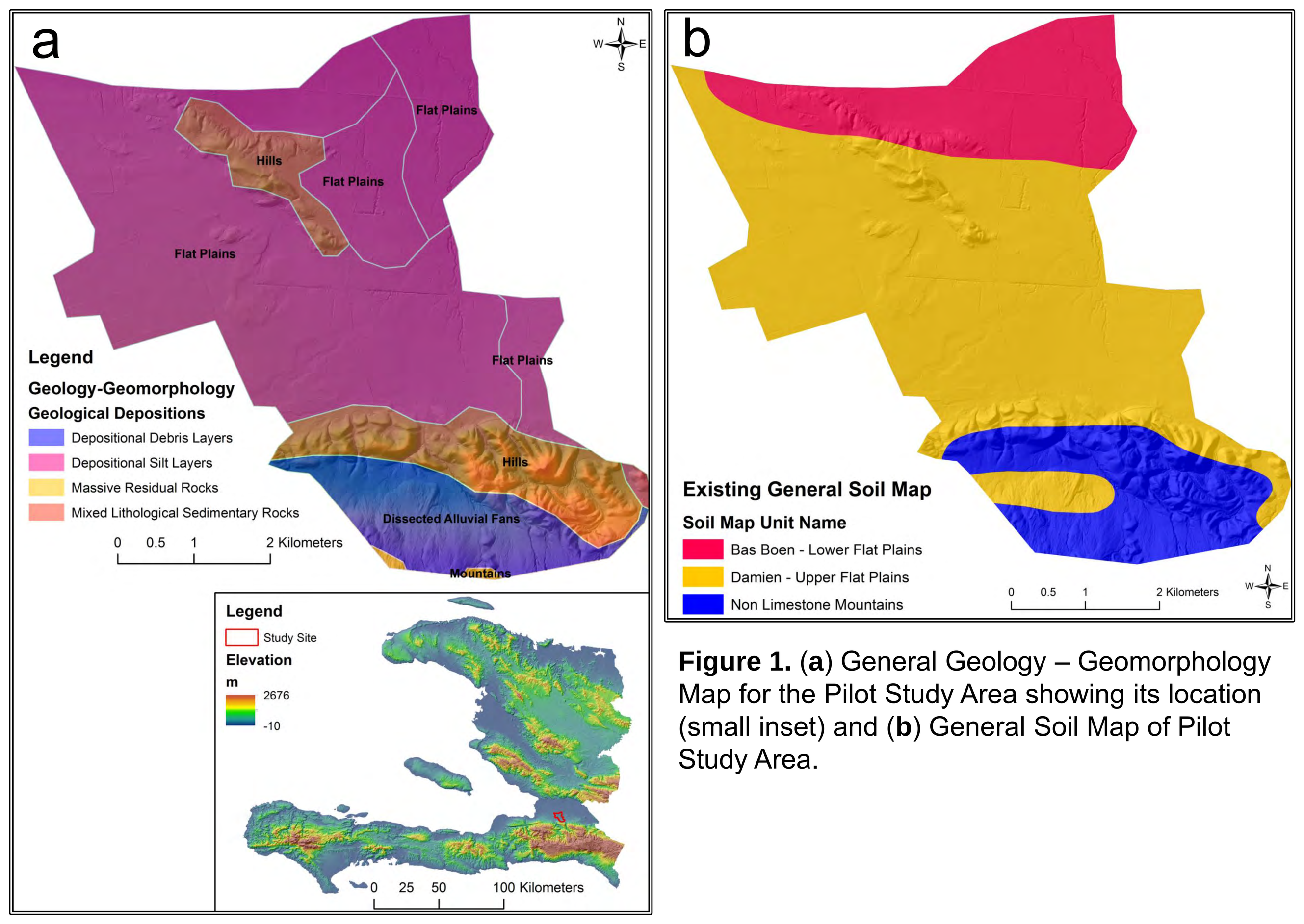

Figure 1. (**a**) General Geology – Geomorphology Map for the Pilot Study Area showing its location (small inset) and (**b**) General Soil Map of Pilot Study Area.

The objectives of the Pilot Study Project were to:

(a) Generate a detailed soil map (1:24,000) for a 3000 ha Pilot Study Area;

(a) Combine Traditional Soil Survey and Digital Soil Mapping approaches;

(a) Develop capacities in Haiti for conducting future soil surveys at national scale.

Materials and Methods

Study Area General Characteristics

Pilot Study Area in located in Cul de Sac valley which is situated between tectonically uplifted mountain ranges. The valley has been filled with marine and erosional deposits. The southern part of the study site is located at the foothills of mountains and expands north toward the central Cul de Sac valley (**Figure 2**).

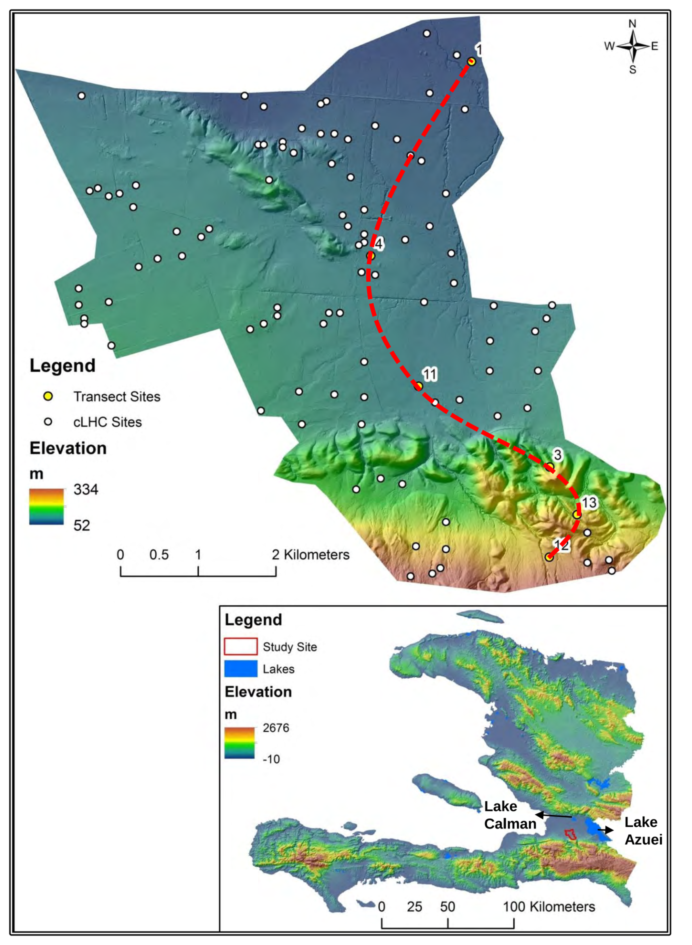

Figure 2. Elevation of Pilot Study Area and the location of field sample sites and transect sites.

Pilot Study Area is characterized by high relief with elevations ranging from 130 to 330 meters above sea level.

The climate for the Cul de Sac is tropical but varies with elevation. The Cul de Sac area is relatively warmer and dryer with mean annual temperature of 26.2°C and the mean annual precipitation was 740 mm. The annual rainfall distribution shows two distinct rainy seasons April–June and October–November.

Soil Survey

The soil survey was conducted based on a combination of traditional and digital soil mapping approaches accompanied by field observation, data collection, soil sampling, and laboratory analysis of physical and chemical properties.

Elevation Data Processing

The LiDAR elevation 1x1 m pixel size was smoothed and resampled using a 3x3 neighborhood low pass filter (Richards, 1986) followed by a bilinear resampling to 5x5 m pixel size in ArcMap 10.2 (ESRI, 2013). This was necessary to highlight trends in morphometric surface features by reducing noise in the data introduced by anthropogenic influence such as roads and man-made ditches.

Soil Pre-Mapping and Site Sampling Selection

A preliminary digital soil map was developed from slope, curvature, and elevation using hill-climbing clustering algorithm (Rubin, 1967) using System for Automated Geoscientific Analysis (SAGA) (Böhner et al., 2006). Terrain features were used to highlight major topographic drives and establish soil landscape relationships to predict soil distribution. In order to assure sampling representativeness of preliminary digital soil map units conditioned Latin Hypercube (cLHC) (Minasny and McBratney, 2006) was used to select 99 observation sites based on slope, curvature, and elevation (**Figure 2**).

Soil Sampling and Analysis

At each site characteristics such as slope length and shape; the general drainage pattern; bedrock and parent material depositions; and native and cultivated plants were recorded. Other soil characteristics (color, texture, effervescence) were also described based on standard methodology (Schoeneberger et al, 2012). 6 representative sites were selected for a full pedon characterization and laboratory analysis (**Figure 2**). Soils were sampled based on the field-identified horizons for chemical and physical analysis at the USDA-NRCS Kellogg Soil Survey Laboratory in Lincoln, Nebraska, USA.

Results and Discussion

Soil Types

Based on the observed and measured field site and soil characteristics, 11 soil types were identified (**Table 1**).

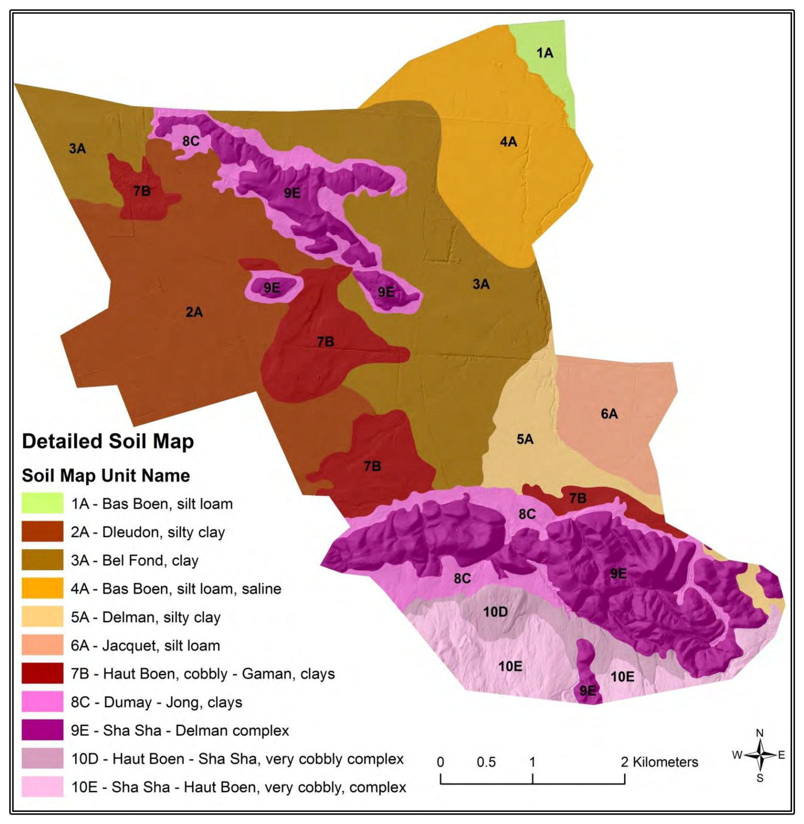

Figure 3. Detailed Soil Map and the distribution of soil types.

Table 1. Taxonomic Classification of soils in the study area.

Soil Name	Taxonomic Classification
Bas Boen	Coarse-silty, carbonatic, isohyperthermic Fluventic Haplustepts
Bel Fond	Fine, smectitic, superactive, isohyperthermic Torrertic Calciustolls
Delman	Fine, smectitic, isohyperthermic Calcidic Haplustalfs
Dleudon	Fine, carbonatic, isohyperthermic Torrertic Calciustolls
Dumay	Clayey over loamy-skeletal, smectitic over mixed, superactive, isohyperthermic Aridic Argiustolls
Gaman	Clayey over loamy-skeletal, smectitic over mixed, superactive, isohyperthermic Calcidic Argiustolls
Ganthier	Coarse-silty, carbonatic, isohyperthermic Aridic Haplaustepts
Haut Boen	Loamy-skeletal, mixed, superactive, isohyperthermic Aridic Argiustolls
Jacquet	Coarse-silty, carbonatic, isohyperthermic Fluventic Haplustepts
Jong	Fine, smectitic, isohyperthermic Torrertic Argiustolls
Sha Sha	Loamy-skeletal, carbonatic, isohyperthermic, shallow Petrocalcic Calciustolls

Most of the soils in the study area were Mollisols and Inceptisols (**Table 1**). Mollisols occurred on Depositional Upper Flat Plains and Hills and Dissected Alluvial Fans while Inceptisols, occurred on the Depositional Lower Flat Plains (Map Units 1A, 4A, 5A, and 6A) (**Figure 3**). A combination of relatively dry climate and Ca-rich materials such as limestone bedrock lead to the formation of Ca deposits such as calcareous gravel and Ca enriched alluvium deposits (**Figure 4**). The soil texture for the majority of the soils was fine/clay and silty/loamy. Soils on the Flat Plains were mostly fine except for Bas Boen that was coarse silty most likely due to its proximity to the marine deposits associated with Lake Azuei and Calman (Figure 2, inset). Soils on Hills and Dissected Alluvial Fans were mostly loamy-skeletal (Sha-Sha) or clay over loamy -skeletal (Dumay, Gaman) due to the abundance of cemented calcareous gravel.

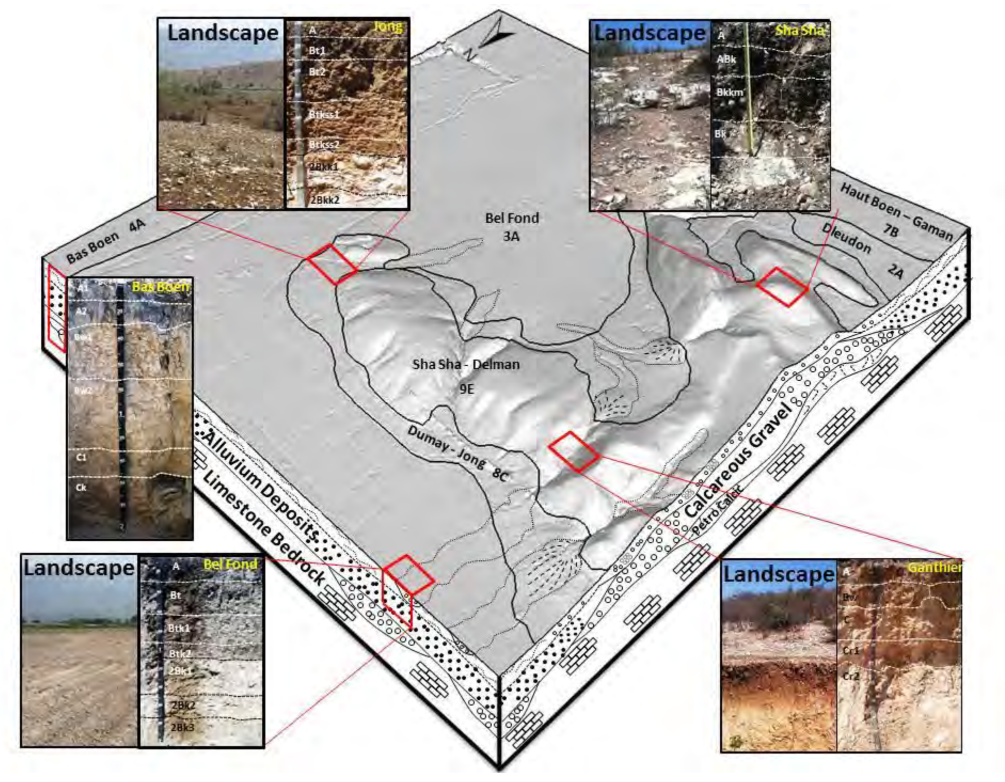

Figure 4. Soil-Landscape relationships in the study area and the underlying parent material deposits.

Soil Physical and Chemical Properties

The presence of Ca enriched materials and salts especially sodium was reflected by the measured soil chemical properties (**Table 2**). Overall, the total clay for all soils combined was 40%, however, CaCO3 clay accounted for one fourth of the total amount. Generally clay decreased with depth while CaCO3 clay did not always follow the same trend.

Table 2. Summary of Chemical-Physical properties for selected soils.

Site ID	Soil Horizon	Profile Depth	Total Clay	CaCO3 Clay	Sand	Silt	Rock Fragments	CaCO3 <2mm	CaCO3 <75mm	Organic Carbon	pH	EC	SAR/ Exch Na
		cm					%					dS m-1	%
1	Bas Boen	200	25	16	54	21	--	--	--	1	10	9.38	102/60
3	Sha-Sha	68	35	13	20	45	57	42	43	4	8	0.35	--
4	Bel Fond	200	45	14	41	15	7	38	--	1	8	0.24	--
11	Delman	200	28	12	45	27	11	41	46	1	8	0.24	--
12	Sha-Sha	42+	57	10	24	18	58	36	59	5	8	0.71	--
13	Ganthier	104	24	14	46	31	9	75	67	1	8	1.06	8/6
6	Jong	200	53	9	32	15	19	35	36	1	8	5.01	46/46
			39	**12**	**39**	**22**	**22**	**43**	**46**	**2**	**8**	**3**	--

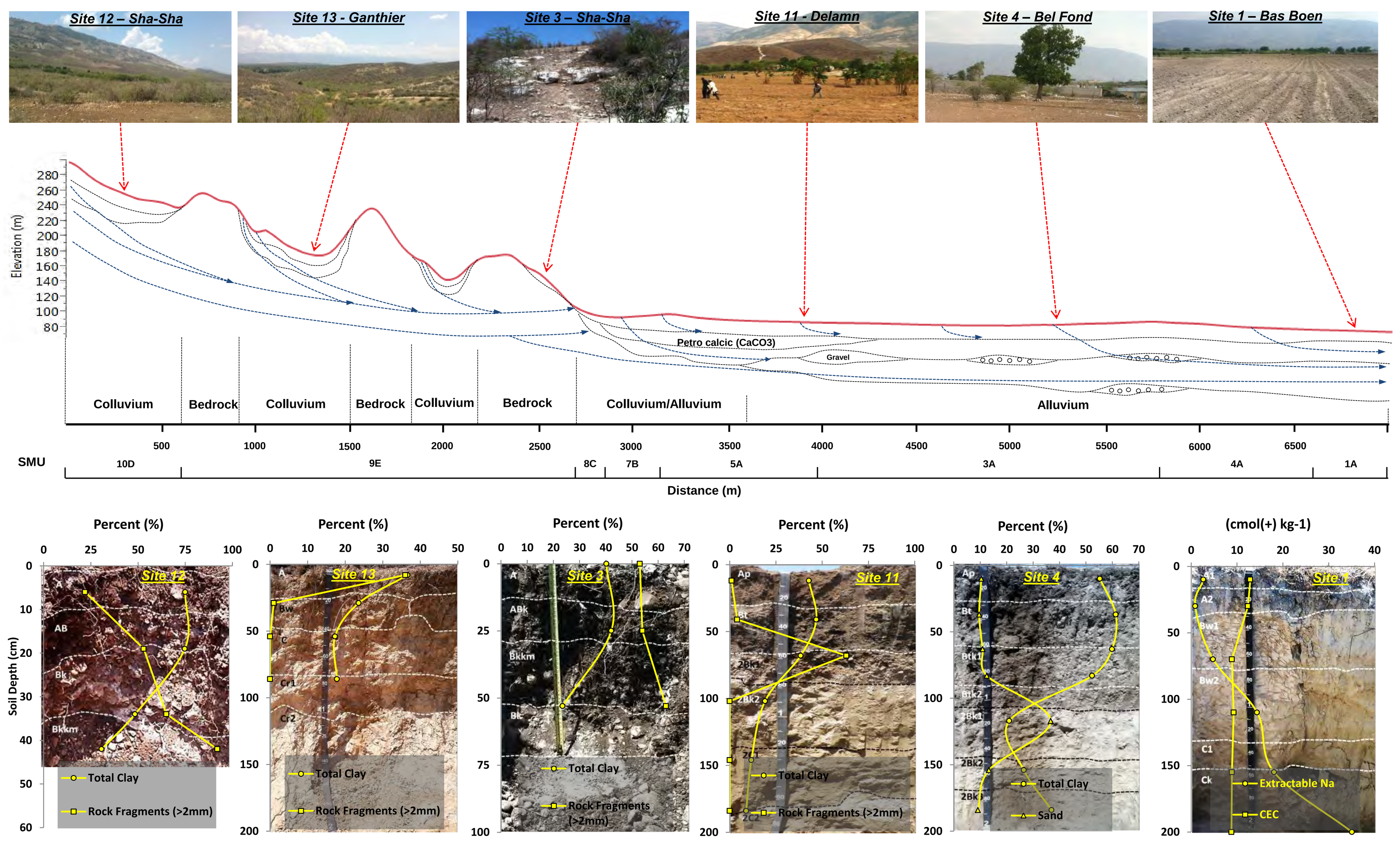

Figure 5. Soil Profiles, their associated landscapes and a conceptual general stratigraphy and water movement following a transect from southeast to northwest direction (see **Figure 3** for transect sites).

Soil Geomorphology

The spatial distribution of soil map units and major morphological differences between soils were closely related to the landscape and stratigraphy of the study area (**Figure 5**). Slope and elevation were the major controls for the differentiation of soils at landscape scale. Based on the slope and elevation the detailed soil map units (**Figure 3**) were aggregated to a new general soil map with three major landscapes representing also three different major geomorphic units Dissected Alluvial Fans and Hills, Upper Flat Plains, and Lower Flat Plains (**Figure 6**).

The soil analytical data coupled with elevation data showed a clear differentiation between Lower Flat Plains that were under the influence of sodium and Upper Flat Plains that were less influenced by sodium. Other studies have also documented the presence of salts in Cul de Sac valley (Schubert, 2012).

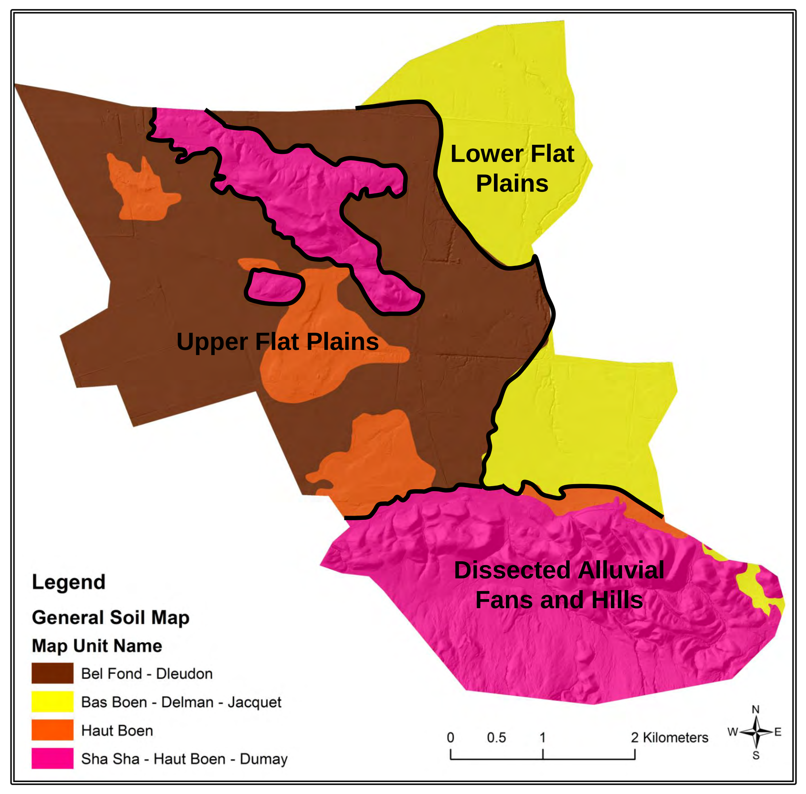

Figure 6. General Soil Map aggregated from the detailed soil map based on slope and elevation.

Soil Behavior - Interpretation

The urban expansion in the agricultural prime farm land in the Cul de Sac valley has increased rapidly, especially after the 2010 earthquake in Port au Prince. Based on soil properties mainly depth to a water table, ponding, flooding, subsidence, linear extensibility (shrink-swell potential), and compressibility the soils in the study area were rated for suitability to support small houses without basement (**Figure 7**). Three categorical ratings were developed "Not limited, "Somewhat limited" and "Very limited" The rating of the soils for construction suitability based on the soil properties and landscape setting confirmed the existing land uses (**Figure 7 a, b**) and highlighted also the potential problems with the most recent construction of houses (**Figure 7c**).

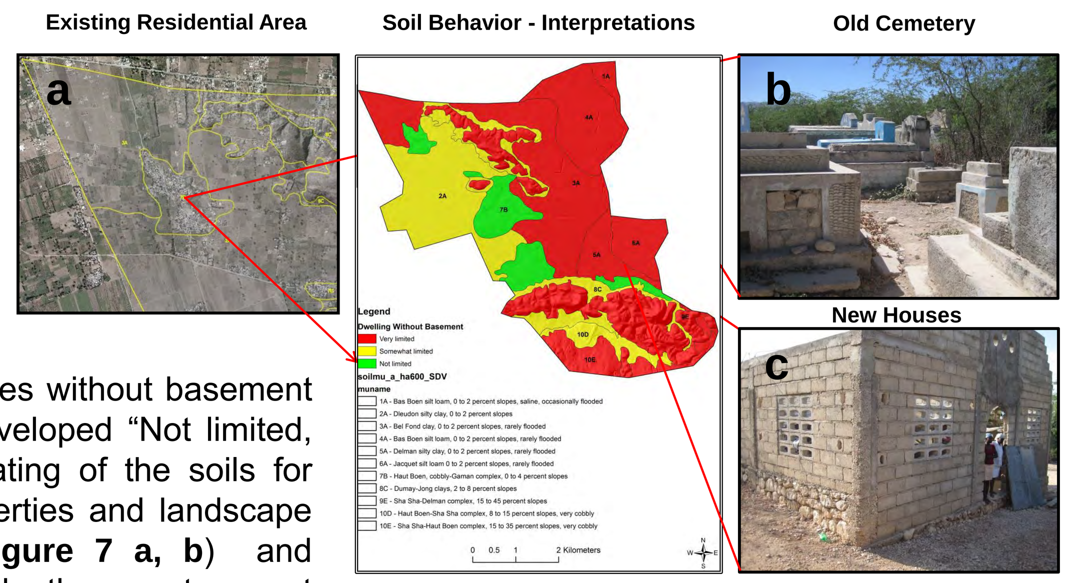

Figure 7. Ratings of map units for construction of dwellings (houses) without basements.

Conclusions

The detailed soil map of the Pilot Study Area highlighted several unique features of the Cul de Sac valley. The Cul de Sac originated from the collision of Caribbean Plate and North America Plate approximately 10 million years ago. Cul de Sac valley was initially submerged under sea water separating the two island north and south but rose steadily as the tectonic plates moved toward each other. The uplift of the limestone sedimentary rocks on both sides of the valley was followed by erosion and deposition process the resulted in the Cul de Sac valley filling with Ca rich materials coating and cementing the gravel deposits. The concentration of water movement toward the valley combined with dryer and warmer climate conditions in Cul de Sac lead to further enrichment of fine sediments with $CaCO_3$ as shown by the chemical soil properties.

The use of cLHC allowed for unbiased and efficient representation of the soil variability in the study area and served as the base for selecting representative sites for full soil characterization and understanding of soil landscape relationships and soil geomorphology based on transects from the selected sites. The soil variability could have been represented by a smaller number of points selected from the cLHC, however this was necessitated due to the need to provide training for 25-30 Haiti soil scientists in order to build capacity in the country for expanding the survey beyond the study area.

Acknowledgements

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