

# Contribution of Remote Sensing Data and GIS to Digital Soil Mapping in a Semi-Arid Zone of North Cameroon (Central Africa)

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**Abstract** Remote Sensing and Geographic Information System methods used to map soils over space and time have numerous advantages over conventional soil mapping techniques which are time consuming, labour intensive, expensive and cover limited areas. In Cameroon, most soil maps were established at small scale using conventional methods and soils units are poorly delineated making it difficult to properly manage soils for various purposes. This study aims to use spectral signatures and GIS techniques to update existing soil maps. The method is based on ETM+ image processing, field investigation and existing data from other maps to update an existing soil map of the Mayo Kani Division in Far North Cameroon. The methodology consisted of interpreting the relationship (colour, organic matter, iron content, texture, moisture content, vegetation, human activities) between soil and satellite images. The main results revealed that delineation of soil units using GIS permitted to establish a soil map and to update soil digital data. Thus, percentages of Vertisols, Ferruginous soils and Halomorphic soils decreased from 38.38, 26.87 and 10.64 to 36.88, 25.67 and 9.13 respectively. Meanwhile, the percentages of less evolved soils, Raw Mineral soils and Hydromorphic soils increased respectively from 14.17 to 16.17, 0.43 to 0.54 and 8.73 to 10.67, while percentage of Fersiallitic soils remained constant, at 0.73. These results reveal that Remote Sensing data and GIS constitute a valuable approach to update existing soil map and to draw digital soil maps. It is recommended that Remote Sensing data be combined with field data to obtain more precise maps.

**Keywords:** Digital soil mapping, GIS, Remote Sensing, soil, semi-arid area, Far North Cameroon.

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## 1. Introduction

Soil plays a very crucial role in supporting ecosystems and human civilization [1]. It is an important natural resource considering its different functions like ecological, technological and socio-economic [2]. In fact, it is solicited for different activities such as food production, human infrastructural support, micro-organism habitats, carbon reservoir and water filter. It is also a memory of human communities throughout history [3]. Although, soil is a natural valuable resource; it is variable in terms of properties, behaviour and spatial distribution determining

its different characteristics and potentialities [1,4]. Regardless of its characteristics, soil undergoes pressure due to mismanagement [5], land degradation expressed by acidification, organic matter depletion, salinization, nutrient depletion and erosion [3] and could affect the viability of infrastructures, ecological food and water security [6]. In this regard, soil resources need to be well known for policy-making, land resource management and sustainable agricultural production [6]. Soil survey is the most popular approach to enable identification of different types of soil units and their geographic distribution is easily determined by mapping [1]. Two techniques of soil survey and soil mapping are usually used including the conventional methods and Geomatics. The Conventional

methods are time consuming, labour intensive and costly while geomatics is most preferred.

Considering the advantages geomatics, using Remote Sensing data and Geographic Information System is very valuable for an efficient and fast soil inventory and mapping as well as at local to global scales [1] for developing countries where soil map and digital soil data at larger scale are lacking for the better exploitation of soil resources soil resources [5]. Geomatics tools are also very efficient and helpful to provide spatially explicit digital data representing the surface features of earth or soil with high precision and synoptic coverage [1]. The development of Remote Sensing and GIS has positively changed the study of soil. They are used for monitoring and evaluation of soil quality [7,4,8,9]. Remote Sensing provides data to enhance existing soil surveys or soil map at local, regional or global scale.

The semi-arid region of Cameroon, fragile ecological zone with poor vegetation cover, highlights some characteristics facilitating the use of Remote Sensing data than in the rainforest where there is no direct relationship between soil and wavelength due to canopy cover. Remote Sensing methods are useful for soil survey, soil suitability mapping, soil erosion and conservation, determination of soil mineralogical composition, soil texture, soil moisture, soil organic matter, soil salinity [1,10,11,12,13] [14,15,16,17,18,19,20,21]. Such modern methods can also help to delineate soil units, deduce soil properties, facilitates digital soil mapping, facilitate access to inaccessible areas, reduce the time and cost compared for conventional soil map [6, 22] and provide a synoptic view of the area [23,24,25,26,27,28]. Therefore, there

exists Radar and optical Remote Sensing systems, airborne and space-borne, with greater area coverage and coarse resolution, to provide soil data at regional scale, while LIDAR, ground-based, monitors with finer resolution [1,7,8]. Optical Remote Sensing data specifically Landsat 7 (ETM<sup>+</sup>) used in this paper is free acquiring and its various applications enabled to characterize soil properties like mineralogical composition, Fe-oxides, organic matter, oil temperature estimation, soil moisture estimation, and the greater area coverage [1].

This article aims to highlight the contribution of Remote Sensing data integrated under GIS for mapping and characterizing soils at various scales in semi-arid area, through the spectral behaviour of soil and its different components derived from RS data. In this regard, it is helpful tool to do digital soil mapping by processing the Remote Sensing data.

## 2. Study Area and Geological Setting

The study area is found in Mayo Kani Division situated in the sudano-sahelian zone in the Far-North Region of Cameroon. It lies between latitudes 10° and 10°40' N and longitudes 14° and 15° E and it covers a surface area of 5110 km<sup>2</sup> (Figure 1). It has a mean annual rainfall between 700 to 850 mm, and has a long dry season from October to April and a short rainy season from May to September, with the maximum in the month of August. The area is covered by a savannah vegetation consisting of woody savannah, shrub savannah, herbaceous savannah and steppe.

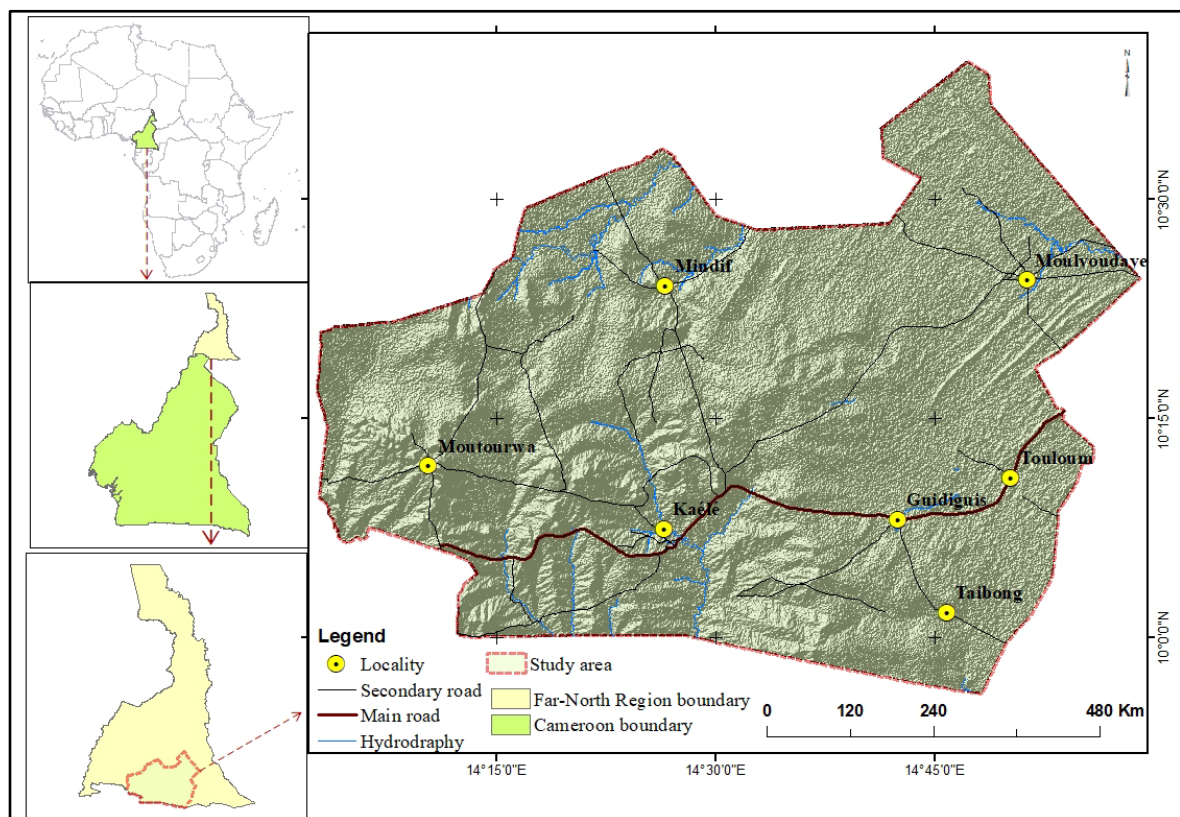


Figure 1. Location of the study area

The study area is a piedmont and floodplain landscape with low altitude (300-500 m) and gentle slope (2%), where inselbergs are sporadically present such as the Lara Mountain (690 m), Mindif Mountain (709 m) and the Moutourwa Mountains (650 m), and further to the East is a sandy plain. There is not enough rivers to flow all rainfall and Mayo Kani River is the main collector. The main soils are Ferruginous soils, Vertisols, Halomorphic soils, Hydromorphic soils, Lithosols and Regosols; less evolved soils, fersiallitic soils [29,30]. The basement consists of Precambrian and volcanic formations comprising granite, gneiss, rhyolite [31,32], and sedimentary substratum from Quaternary constituted of sandy, clayey or sandy-clayey alluvia [31,33,34].

### 3. Data Collection Methods

#### 3.1. Remote Sensing Data

The datasets used include existing soil map (1:200 000), geological map (1:1 000 000), topographic map (1:250 000), STRM and ETM<sup>+</sup> imageries and data from field investigation. The Landsat ETM<sup>+</sup> located to pathrow 184053, was downloaded from USGS site via this link: <http://earthexplorer.usgs.gov/> during the month of February 2003, period of dry season without clouds and so appropriate for good quality of Landsat imagery. Chosen for direct and indirect relationships between spectral signature data and soil properties such mineral composition, colour, texture, salinity, carbonate content, vegetation, organic matter, moisture, iron content, erosion [3,6,35,36,37,38], ETM<sup>+</sup> imagery has eight spectral bands with spatial resolution of 30 m (Bands 1,2,3,4,5 and 7), 60 m (band 6) and 15 m (panchromatic band) (table 1).

Table 1. Characteristics of Landsat 7 of the study area

| Bands            | Spatial resolution (m) | Wavenumber (μm) | PathRow | Sensor           |
|------------------|------------------------|-----------------|---------|------------------|
| Blue             | 30                     | 0,45-0,52       | 184053  | ETM <sup>+</sup> |
| Green            | 30                     | 0,52-0,60       |         |                  |
| Red              | 30                     | 0,63-0,69       |         |                  |
| Near Infrared    | 30                     | 0,77-0,90       |         |                  |
| Mean Infrared 1  | 30                     | 1,55-1,75       |         |                  |
| Mean Infrared 2  | 30                     | 2,09-2,35       |         |                  |
| Thermal Infrared | 60                     | 10,40-12,50     |         |                  |
| Panchromatic     | 15                     | 0,50-0,67       |         |                  |

#### 3.2. Soil Data

In the course of this study, a field investigation was carried out and sites were chosen on a topographic map (1: 200 000). Several pits were dug across the study area, but seven representative profiles were selected according to topographic and geomorphological positions, and lithological basement, for further morphological and analytical characterisation. Geological and topographic maps were used to determine the lithological basement and the position of soil units in landscape, respectively. The morphological characterization consisted of determination of colour (Munsell code charts), texture and

structure. The analytical characterization was focused on organic matter, moisture, pH, CEC and iron content. An indicative soil map was then established based on soil features, topographic position, geomorphology and lithological basement (Figure 2).

#### 3.3. Satellite Imagery Processing

The indicative soil maps were used to get a digital soil map. Indeed, the different soils' groups such Vertisols, Ferruginous soils, Halomorphic soils, Fersiallitic soils, Less Evolved soils, Hydromorphic soils and Raw Mineral soils, have been previously identified on an existing soil map [29]. Envi 4.5 software was used for satellite imagery processing and a thorough processing was done. Soil units were individualized from true coloured composition (321) and false coloured composition (742). Each soil unit was then characterized by its colour, mineral composition, moisture, organic matter, texture and morphology through spectral signatures and surface covering such as vegetation [6] meanwhile SRTM used in ArcGIS 10.3 allowed the obtention of topographic and geomorphological maps showing position of the different soil units on landscape. Landsat ETM<sup>+</sup> was used for direct visualization like colour, texture, morphology, organic matter content, moisture and lithological basement of soils and soil spectral behaviour was determined according to spectral signatures. Soil unit boundaries were delineated considering the above discriminating features (Figure 2). Furthermore, the complete soil map was established by superimposition of the soil maps drawn from field data investigation and satellite imagery (Figure 2). Soil nomenclature was done according to the French classification [39].

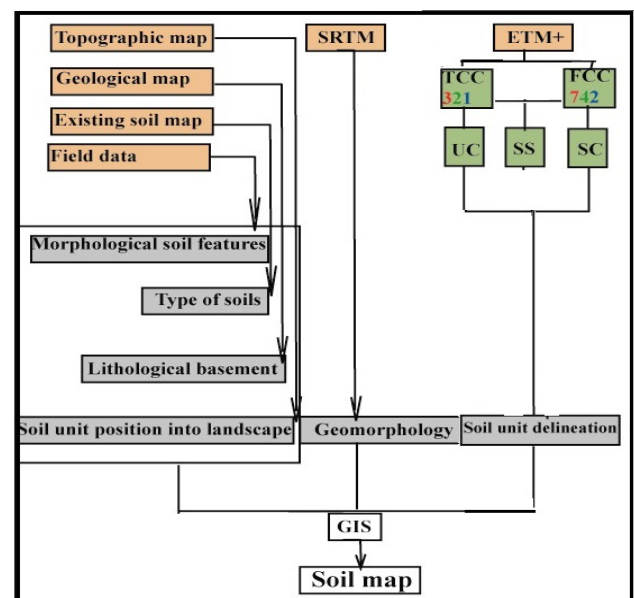


Figure 2. Methodological scheme of soil mapping

### 4. Results and Discussion

#### 4.1. Morphostructural Characteristics of Soils

Field investigations led to the establishment of an indicative soil map from morphological features,

topographic position and rocks as shown below (Figure 3, Figure 4 and Figure 5; Table 2). The Digital Elevation Model (DEM) and topographic map show that altitude ranges between 315 and 680 m and the representative relief is a pediplain; the western part is dominated by inselbergs and mountains while floodplain is the most representative feature at the eastern part; the slope is gentle.

Geological formations are represented by plutonic, metamorphic and sedimentary rocks namely granite, syenite, gneiss, micashist, ancient sand dunes and alluvium.

According to the indicative soil map (Figure 6), Vertisols being the most widespread and located at the western part, are slightly grey; Ferruginous soils are slightly yellow and are situated at the eastern part; Less Evolved soils, reddish grey, are more or less extensive; Halomorphic soils, Hydromorphic soils, Fersiallitic soils and Raw Mineral soils are respectively brownish grey, blue, reddish brown and brownish. Located around 400-500m, Fersiallitic soils are brown reddish (5 YR6/3), clayey, polyhedral and developed on gneissic basement. Raw mineral soils present brownish (7.5YR 4/4) to greyish (10YR 5/21) colour, sandy texture and coarse structure. They occur on granite and syenite and are present at the summit of mountains (400-500 m) (Table 2).

Vertisols are grey (10YR 7/1), clayey to sandy clayey, polyhedral, compact, presence of limestone nodules and the lithological basement consists of gneiss, micashist, granite and syenite around 380-465m altitude (Figure 7).

Ferruginous soils are brownish yellow (10YR5/4), sandy and coarse, less compact; red stains and black nodules are observed at the bottom, the substratum is clay and sand alluvium and their topographic position is relatively comprised between 320-360m (Figure 8). From top to bottom, three horizons are observed:

Mainly situated at 340-425 m, Halomorphic soil are brownish grey (2.5 Y4/4), clayey to sandy-clayey, massive to polyhedral, and the basement consists of clay and sand alluvia (Figure 9).

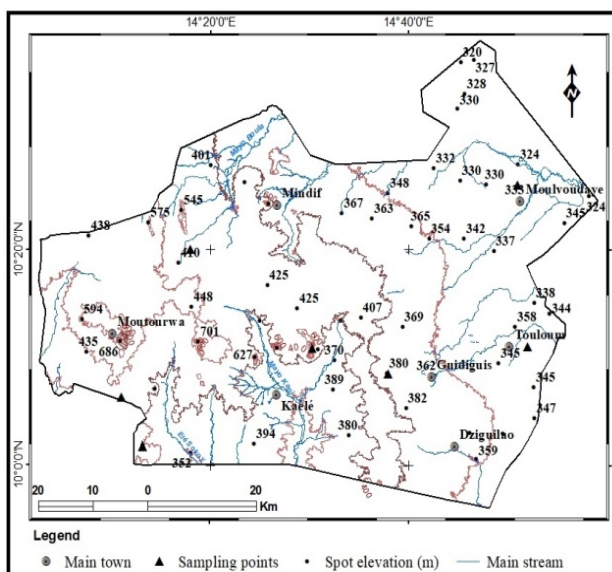


Figure 3. Topographic map (SRTM)

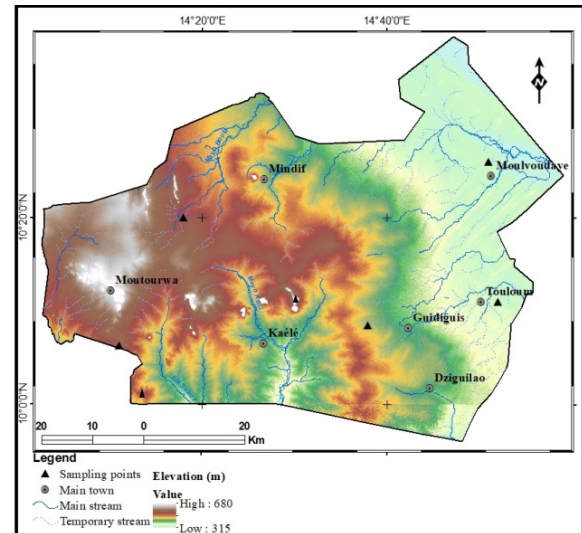


Figure 4. Elevation map (SRTM)

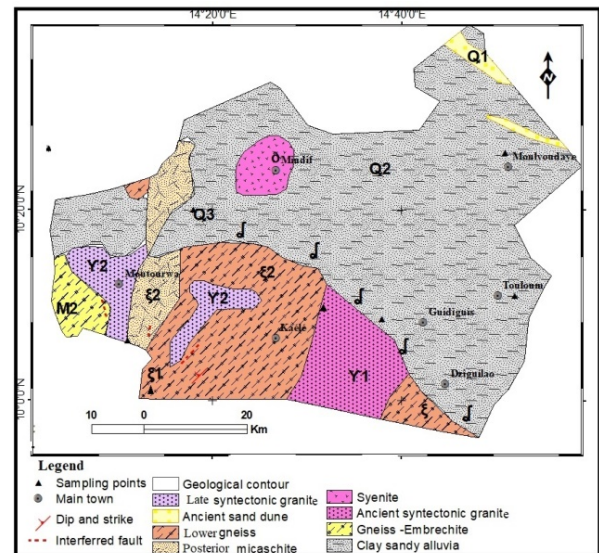


Figure 5. Geological map [40]

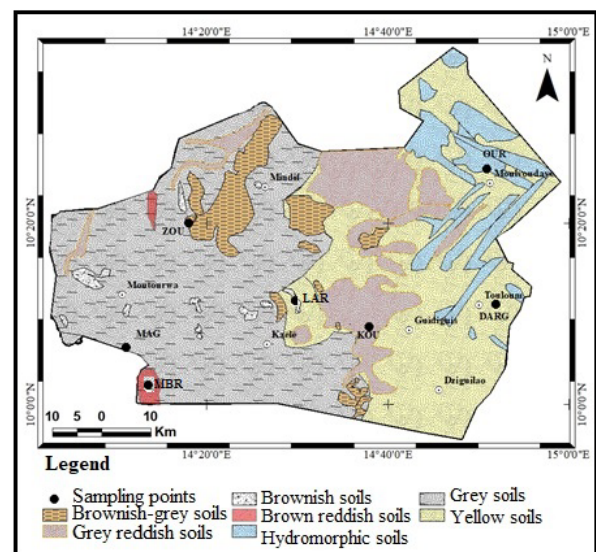


Figure 6. Indicative soil map

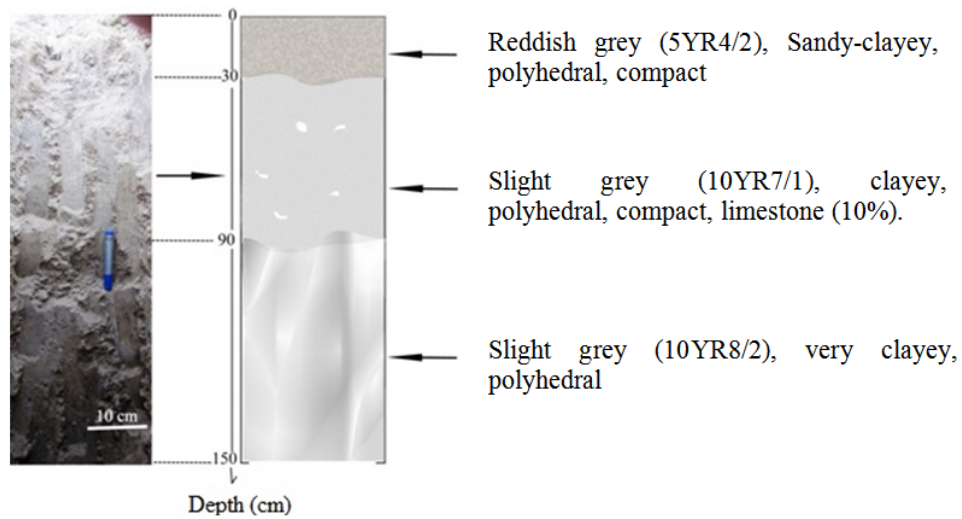


Figure 7. Morphostructural organisation of Vertisols

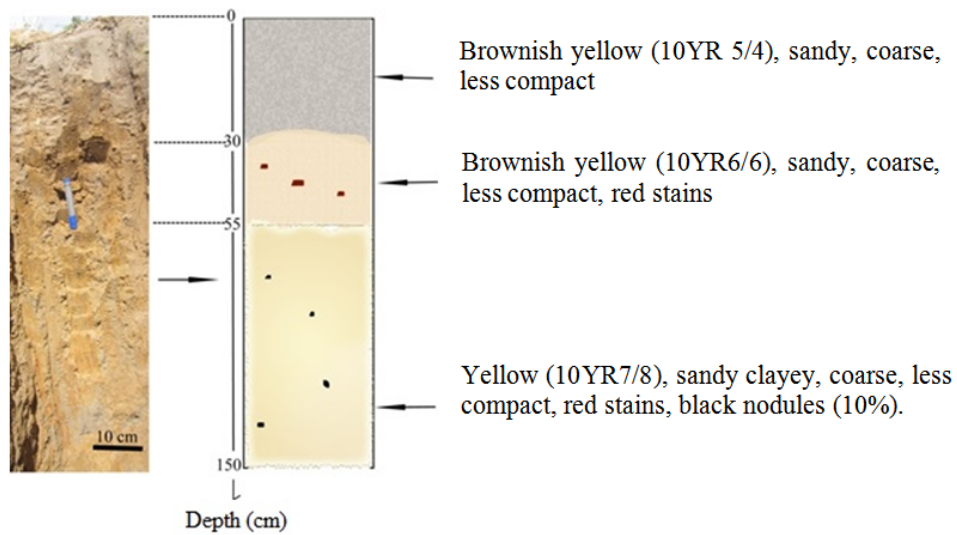


Figure 8. Morphostructural organisation of Ferruginous soils

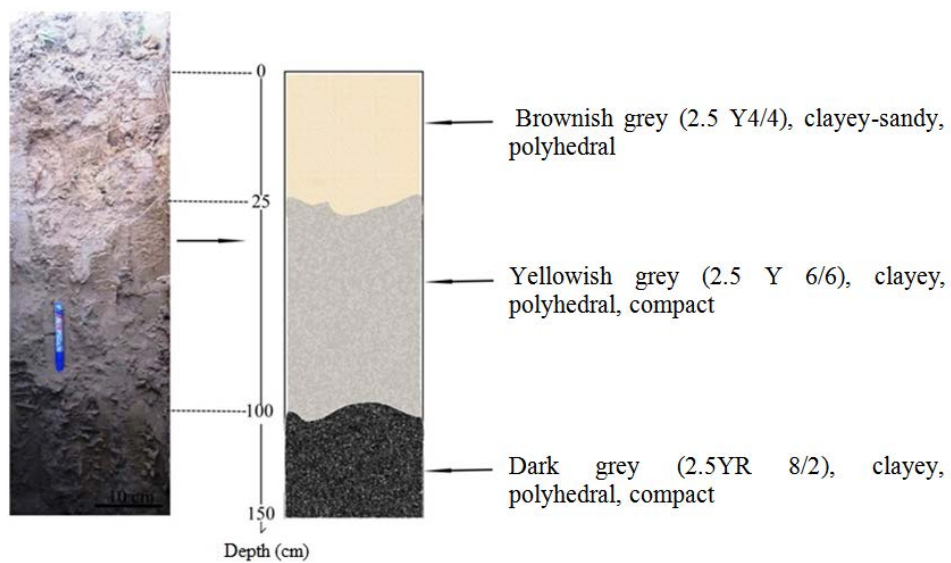


Figure 9. Morphostructural organisation of Halomorphic soils

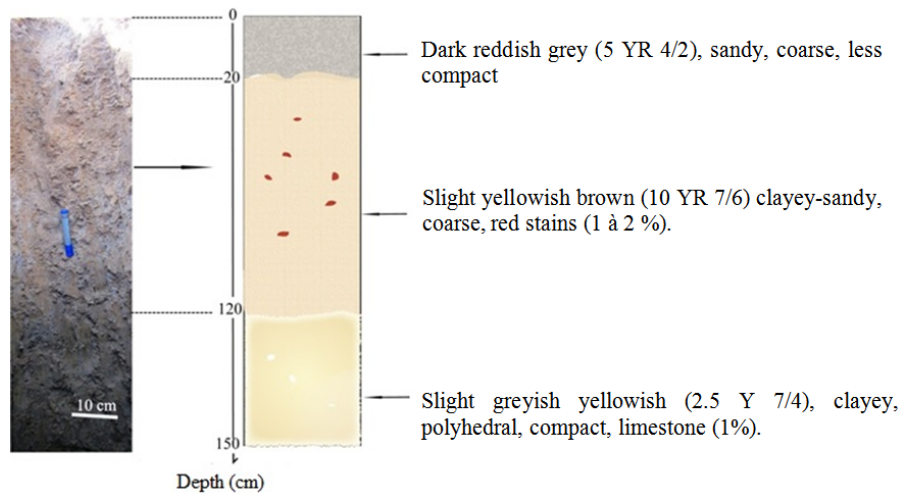


Figure 10. Morphostructural organisation of less Evolved soils

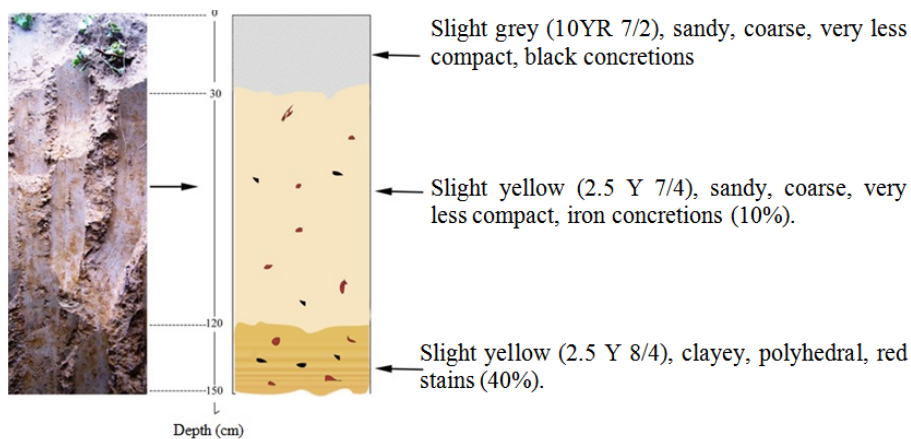


Figure 11. Morphostructural organisation of Hydromorphic soils

From top to bottom, less evolved soil is characterized by a grey reddish (5 YR 4/2) colour, sandy-clayey texture, coarse to polyhedral structure; red patches are observed at the bottom; they are formed on clay and sand alluvia at a topographic position around 380-425 m (Figure 10).

Located at low position (320-340 m), Hydromorphic soil highlights slight grey (10YR 7/2) to yellow reddish (2.5Y7/4) colour, sandy to sandy-clayey texture and coarse to polyhedral structure, some red stains and concretions are observed; the substratum is clay and sand alluvia (Figure 11).

## 4.2. Satellite Image Interpretation

### 4.2.1. Direct Interpretation: Colour, Form and Texture

The true composite (321) and false composite (742) of ETM<sup>+</sup> (Figure 12 and Figure 13) show some essential soil features. The descriptive analyses of soil properties are focused on their colour, form, texture and spectral signatures which are influenced by their components [6,41]. Thus, Fersiallitic soils located at SW and NW, are grey greenish, appear with polygonal forms and fine texture, while Vertisols are grey brownish or bluish and blurred with fine texture. Halomorphic soils are light purple with polygonal form and fine texture. Less evolved soils present white colour, distribution and light rough texture. Besides, hydromorphic soils, with black colour, present an extended form alongside the sand dunes, upon

which are Ferruginous soils which are yellow brownish. Raw mineral soils are black and sparsely observed. Nevertheless, as displayed on Figure 7 and Figure 8, the TC 321 allows separate visualizing of the groups of soils as they are covered by weak vegetation in FC 742.

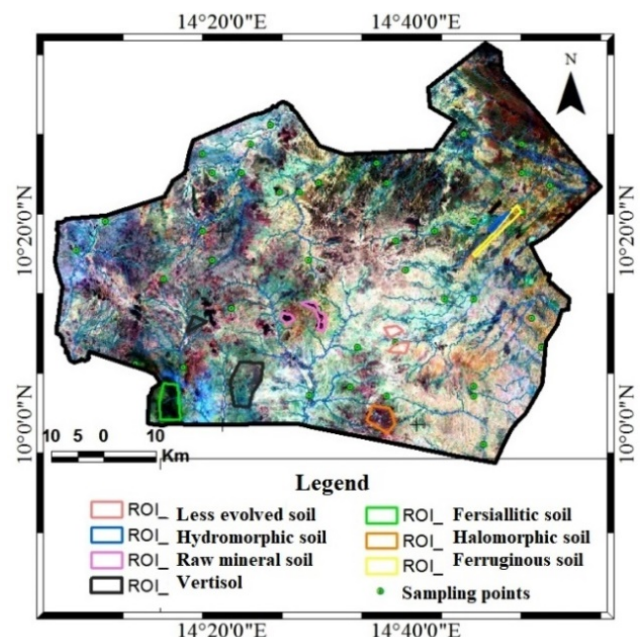


Figure 12. True composite image (321)

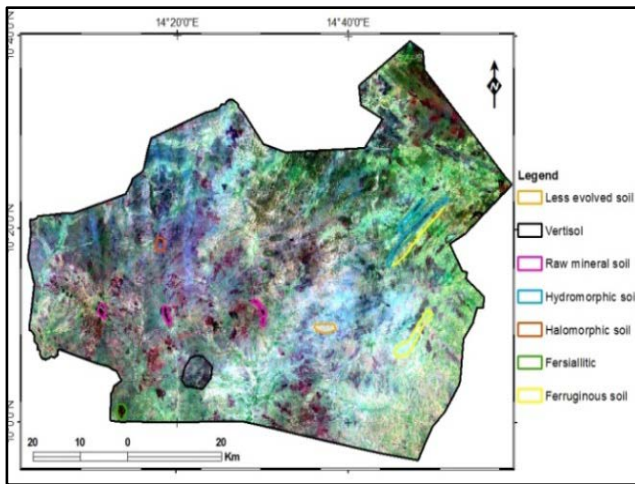


Figure 13. False composite image (742)

#### 4.2.2. Indirect Interpreting: Soil Spectral Signature

Soil spectral behaviour is not absolutely a direct relationship between soil and issue of Remote Sensing and should be understood via indirect interpretation [42]. In terms of spectral behaviour (Figure 14), each soil is characterized either by reflectance or absorption which increases or decreases in visible or infrared domains, depending on colour, particle size distribution, structure, moisture, organic matter content, iron oxide and covering vegetation [35]. Ferruginous soils and Fersiallitic soils highlight an increasing monotone spectral response in visible domain which remains relatively high in infrared domains, compared to other soils. This difference of strong reflectance of Ferruginous soils and Fersiallitic soils is due to the red colour and high sand content [35,43]. Their yellowish (10 YR 5/4) to brown reddish (5 YR 6/3) coloration influence reflecting response, for they absorb less energy than Vertisols and Hydromorphic soils whose high organic matter and high moisture content, would favour energy absorption [44,35]. On the contrary, all other soils present a strong absorption as well as at band 3 of visible and near infrared domains. This is related to their dark coloration, high clay content, high moisture content, organic matter content and iron oxide content [35,44,43]. Besides, less evolved soils, present a slight reflecting response as well as in the visible and infrared domains, due to the fine particles [35]. It is also noted that all soil units have the same weak and strong reflecting spectral behaviour respectively at band 3 of visible and Near Infrared [43,44,45]. It is related to the weakness of the vegetation cover as shown in Figure 14 [35,46,47,48]. Furthermore, despite the black colour signed by Hydromorphic soils and Raw Mineral soils, the former presents a strong reflecting response at band 3 than the latter (Figure 14). This spectral behaviour is related to the high content in ferromagnesian elements in the raw mineral soils [35]. Finally, dark coloration, high clay content, high moisture content, organic matter content and iron oxide

content decrease spectral reflecting response meanwhile sandy fractions and clear coloration increase spectral.

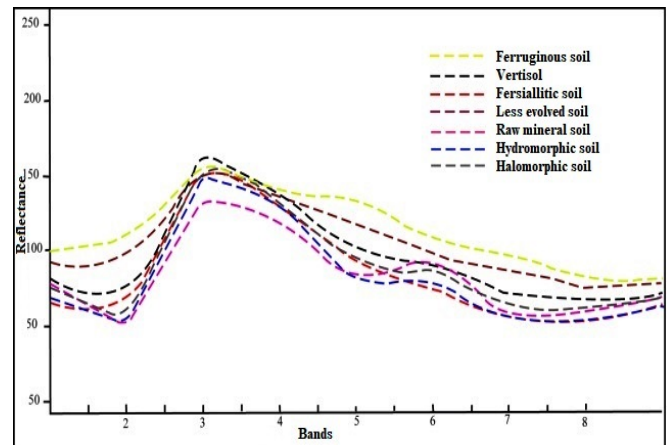
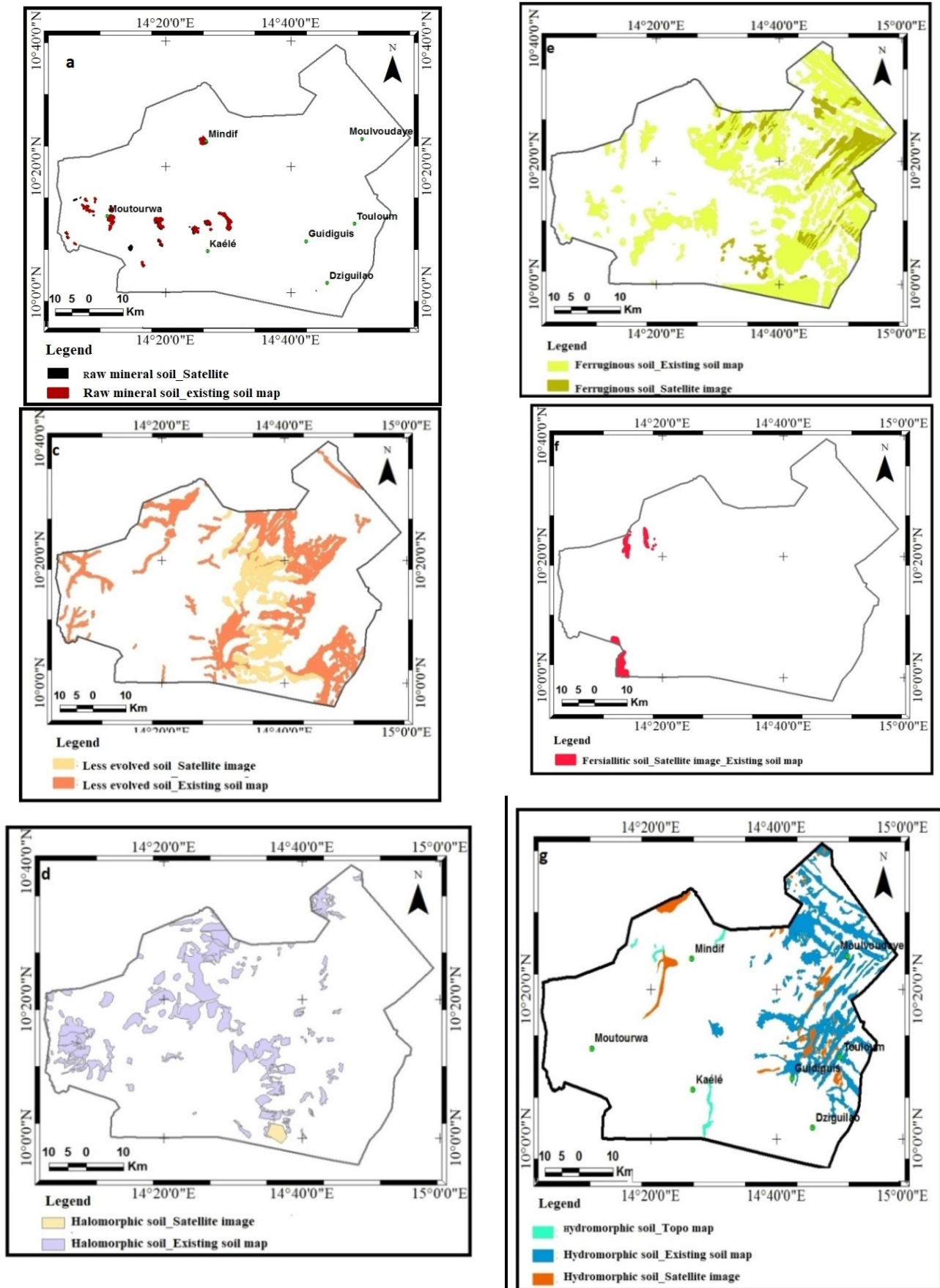


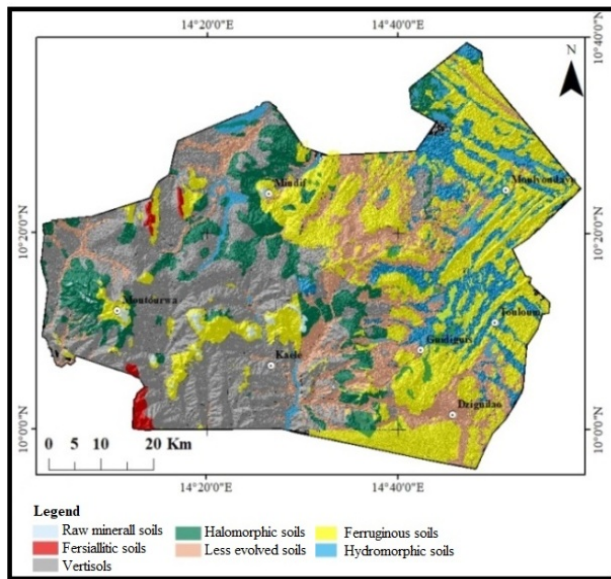
Figure 14. Soil spectral signatures

#### 4.3. Delimitation of Soils Units

The delimitation of the soil boundaries was based on the composite images obtained from 321 and 742 combinations which allow discriminating soil boundaries and transition between soils units according to colour, topography, geomorphology and lithological basement (Figure 3, Figure 4 and Figure 5). Indeed, delineation of soils boundaries (figs 15 a, b, c, d, e, f and g) shows that Vertisols are mainly located at western parts, occupy a topographical position varying between 380-465 m (Figure 3 and Figure 4) and are made up on various granite, gneiss, gneiss-embranchite and micaschist (Figure 5). Excepting Fersiallitic soils and raw mineral soils whose lithological basement is gneissic and granitic, Ferruginous soils respectively, Less Evolved soils, Hydromorphic soils and Halomorphoc soils are extended on low topographic position and sandy or clayey alluvium which constitutes the main substratum (Figure 3, Figure 4 and Figure 5). The final digital soil map obtained through Remote Sensing data and GIS is presented in Figure 16. The soil boundaries are more clearly defined than on the previous existing soil map, and more precisions are brought as indicated in Figure 17. Vertisols remain the most widespread soil unit with 36.88% versus 38.38 in the previous soil map; followed by Ferruginous soils, 25.37% versus 26.87; Less Evolved soils, 16.67 % versus 14.17; Hydromorphic soils, 10.67% versus 8.73; Halomorphoc soils, 9.13% versus 10.64% and finally, Raw Mineral soils with 0.54% versus 0.43. Therefore, the percent of Fersiallitic soils remains constant, 0.53%. These change results from using data as well as from Remote Sensing, topographic map and field investigation [36,37]. Furthermore, delineating of soils boundaries from Remote Sensing data based on the colour was not influenced by vegetation. According to [36], soils spectral features are predominating on vegetation cover if it is less than 30%.



**Figure 15.** Soils units delineation (a) Raw mineral soil; (b) Vertisols; (c) Less Evolved soil; (d) Halomorphous soil (e) Ferruginous soil; (f) Fersiallitic soil; (g) Hydromorphic soil



**Figure 16.** Digital soil map obtained from Remote Sensing data and GIS

The superimposition of the different soil units delineated essentially permitted the obtention of a soil map (Figure 16) from satellite data; it is richer than previous soil maps in terms of soil boundaries, larger scale and transition. These results are similar to those of other authors [36,37,43,49,50,52]. In fact, the soil map obtained by superimposition of an indicative soil map from field work and the map from satellite imagery has an improved aspect. According to [5], it overcomes the limitations of traditional soil surveys whose soil map is drawn up by representing horizons [36] and the spectral

characterization limited to the topsoil [5]. Furthermore, its proceeding steps are shorter and simpler regarding the procedure set up by [53] which consists to establish a soil map by using iterative approach. It highlights a great advantage by its objectivity and to be easily reproduced within environmental and biophysical features similar to semi-arid zone [54].

## 5. Conclusion

This study aimed to assess the contribution of satellite imagery data and GIS to draw a digital soil map in a semi-arid area of North Cameroon. The methodological approach set up by combining field investigation data and Remote Sensing data permitted to characterize land cover and intrinsic data soils. Delineation of soils units using GIS permitted to draw the soil map and to update soil digital data. Thus, the percentage of Vertisols, Ferruginous soils and Halomorphic soils decreases from 38.38, 26.87 and 10.64 to 36.88, 25.67 and 9.13 respectively. Meanwhile, the percentage of less evolved soils, Raw mineral soils and Hydromorphic soils increases from 14.17 to 16.17, 0.43 to 0.54 and 8.73 to 10.67 respectively, while that of Fersiallitic soils remains constant, at 0.73. Finally, Remote Sensing data and GIS constitute a great approach to update existing soil maps and to draw digital soil maps. Therefore, for more precise maps to be obtained, Remote Sensing data needs to be combined with field investigation data.

**Table 2. Physical characteristics of soils from the study area**

| Soil type         | Soil profile | Lat.     | Long.     | Alt. (m) | Colour                                  | Moisture (%) | OM (g/kg) | Fe <sub>2</sub> O <sub>3</sub> (%) | Texture             | Structure          | Lithology                            |
|-------------------|--------------|----------|-----------|----------|-----------------------------------------|--------------|-----------|------------------------------------|---------------------|--------------------|--------------------------------------|
| Vertisol          | Magada       | 10°15'N  | 14°11' E  | 380-465  | grey (10 YR 7/1)                        | 8,34         | 6,45      | 4,64                               | clayey              | Polyhedral         | gneiss, micaschist, granite, syenite |
| Ferruginous soil  | Dargala      | 10°11'N  | 14°52' E  | 320-360  | yellow (10 YR 5/4)                      | 0,41         | 4,07      | 2,15                               | sandy               | Coarse             | Clay and sand alluvia                |
| Fersiallitic soil | Mboursou     | 10° 04'N | 14°12'E   | 400-500  | brown reddish (5 YR 6/3),               | /            | /         | 20                                 | clayey              | polyhedral         | gneiss                               |
| Raw mineral soil  | Lara         | 10°13'N  | 14°29'E   | 400-500  | brownish 7.5YR 4/4- greyish (10YR 5/21) | /            | /         |                                    | sandy               | Coarse             | granite, syenite                     |
| Less evolved soil | Kourbi       | 10° 08'N | 14°38'E   | 380-425  | grey reddish (5 YR 4/2)                 | 2,04         | 3,86      | 1,35                               | Sandy-clayey        | Coarse-polyhedral  | Clay and sand alluvia                |
| Hydromorphic soil | Ouro Bello   | 10°56' N | 14° 51' E | 320-340  | yellow reddish (2.5 Y 7/4)              | 12,87        | 0         | 3,57                               | Sandy-clayey        | Coarse-polyhedral  | Clay and sand alluvia                |
| Halomorphic soil  | Zouzoui      | 10°23' N | 14°18'E   | 340-425  | grey brownish (2.5 Y4/4)                | 0,91         | 2,91      | 4,79                               | Clayey-Sandy-clayey | Massive-polyhedral | Clay and sand alluvia                |

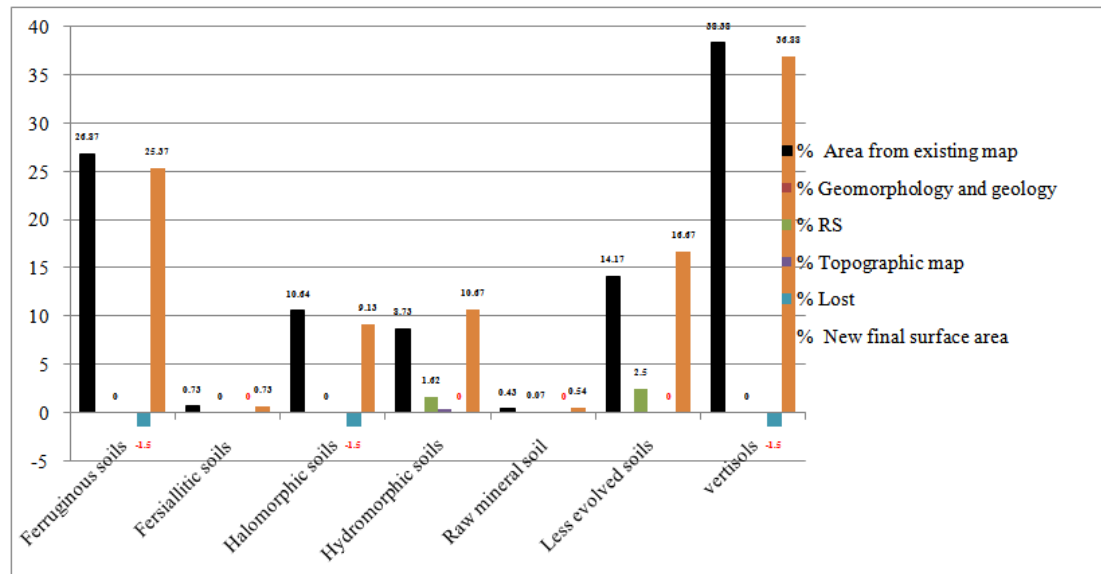


Figure 17. Percentage of soil units

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