Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.6, No.2, 2016

A Study of Holomorphic Soil in SuleTankarkar Local Government Area of Jigawa State Using Remote Sensed Data

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The research is financed by TETFUND Abuja, Nigeria with REF. NO. FUD/URCP/02/04/14

Abstract

This study is carried out to examine Holomorphic soil formation in one of the local Government Areas of Jigawa State – SuleTankarkar LGA. Unsupervised random sampling technique was used to select the sampling sites from the five districts that make up the Local Government. Global Positioning System (GPS) was used in the field for data collection. The sample soils collected were taken to laboratory for physicochemical analysis unto which the textural classes and electrical conductivity (EC) of the soils were measured. The results for EC measurement ranges from 8.22µS/cm – 63.7µS/cm with lowest figures at Danladi site 1 and the highest figures occurs at Danzomo site 1. The textural class measurement revealed that Dangwanki site 2, Jeke site 1 and 2 were classified with sandy soil. Danladi site 2, Danzomo site 1 and SuleTankarkar site 2 falls under sandy loam type. While Dangwanki site 1, Danladi site 1, Danzomo site 2 and SuleTankarkar site 1 were classified with loamy sand. The 36 Normalized Difference vegetation Index (NDVI) data sets utilized for the study were recomposed into 4 Multiple Value Composites (MVCs) and then reclassed to derive the bare soil images used for the GIS analysis. The empirical reflectance method was applied to detect the spatial spectral reflectance pattern of the dielectric properties of the soil. The spectral curves showed that there were existences of holomorphic soil formation from 2000 to 2009, but significantly decrease to 2010. Principal Components Analysis (PCA) for time-series analysis was also incorporated with the used of Standardized principal components. This gave a clear indication of its formation from the components loadings and graphs with about 65% of the areas been affected. Holomorphic soil formation causes changes in agricultural suitability, and declining rate of productivity. It is therefore necessary to construct drainage channels to alleviate flooding and waterlogging, soil nutrient management shall be induced such like application of manures.

Key words: Holomorphic, Electric conductivity, empirical reflectance, principal components analysis

1. Introduction

In semi-arid lands the behavior of rainfall seems to be the most potent feature that results to the formation of holomorphic soil. Rains which fall mostly as torrential and are lost to run-off, with a high rate of potential evaporation leaving the salts that are carried to the surface to crystallize.

Holomorphic soil is one of the sub types of intra zonal soils classified as Aquic Natrustalts and Typic Natraqualfs (Maduakor, 1991.). Intra zonal soils have more or less well defined soil profile characteristics that reflect the dominant influence of some resident factor of relief or parent material (Soil Survey Staff, 1999). Holomorphic soils are formed by the pedogenic process of salinization. The areas where silts and clays make up a large proportion of the soil-body are called holomorphic soil. These are classified into saline soils (containing chlorides, sulphates, carbonates and bicarbonates of sodium, calcium and alkali soils (predominantly sodium salts, especially sodium carbonate NaC03) (Bhaskar, 2009).

Thus, there is an increasing necessity to quantify the formation of Holomorphic soil which is an aspect of soil degradation mainly through the phenomenon of salting. Accumulation of salts may occur naturally in semi-arid lands where direct evaporation from the soil exceeds the amount of rainfall resulting to the depletion of the fertile surface layer of the soil. This can be aggravated by the characteristics of dry climates. Though, the semi-arid climate is associated with wet summers and dry winters where inter annual rainfall varies from 20-50% with averages of up to 700mm (IISD, 1995). This therefore has constituted an important natural factor in the formation of Holomorphic soil in the semi-arid lands.

It is a well-known fact that high concentration of calcium, chlorides, carbonates and bicarbonates of sodium, and sulphates in a body of soil may decrease the soil productivity and as well may change the soil characteristics thus contributing to soil degradation by development of holomorphic zones (Kumar, 2012).
Thus conventional soil sampling and laboratory analyses cannot efficiently provide the needed information, because these analyses are generally time consuming, costly, and limited in retrieving the temporal and spatial variability. In this context, remote sensing (RS) is now in a strong position to provide meaningful spatial data for studying soil properties on various spatial scales using different parts of the electromagnetic spectrum (Hendrik et al., 2015).

In this study, the soils of the study area – SuleTankarkar L.G.A falls in the semi-arid land areas of the State (Jigawa, 2003) were studied using remotely sensed data. Ground inputs technique on the physicochemical characteristics of soils were collected through field work and laboratory investigation to correlate the physicochemical properties with the spectral response as an aid in mapping the soils using remotely sensed data.

2. Materials and Methods

2.1 The Study Area
In this study, SuleTankakar Local Government Area was selected as the study area. This Local Government lies approximately between $12^0\ 21'\ 10''$ and $12^0\ 52'\ 09''$ East Longitudes and $8^0\ 56'\ 37''$ and $9^0\ 24'\ 19''$ North Latitudes covering an area approximately 1,297 square kilometers with highly variable rainfall ranging from 565mm to 787mm per annum (JARDA, 2002-2006). This gave rise to a prominent accumulation of calcium carbonate under the form of individual nodules in the soil profile (Verbeye, 1991), and also the growth of native vegetation of species, such as grasses and grass-like plants, fortes and half shrubs, and also shrubs and scattered trees (Figure 1).

2.2 Samples Collection
Unsupervised sampling technique was applied to obtain the sampling sites from the five districts in the Local Government Area for this study. Abbasi *et al* (2010) Method was adopted for the soil samples collection. Quadrats (15cm by 15cm), hand shovel and ruler were the material used to get the sample amount of the soils at each particular site. The soil was dug from 0 to 15cm deep and collected in plastic bags and taken down to laboratory for analysis. Thus the correct coordinates of each sample site were recorded using Global Positioning System (GPS).

Moreover windowed satellite imageries for the study area from MODIS-NDVI Satellite imageries covering Jigawa State and Environs ranging from 2000, 2004, 2009 and 2010 were used as remotely sensed data. Image processing and GIS analysis were carried using IDRISI Selva software. Also Global Positioning System (GPS) was used to obtain the coordinates of the sample sites.

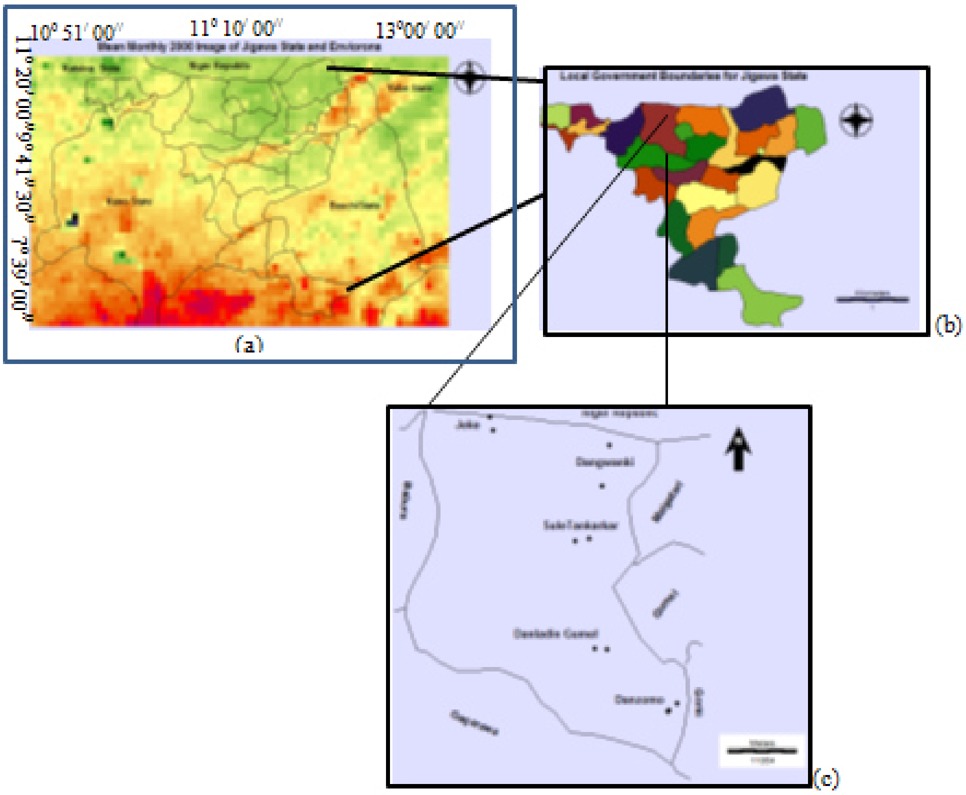


Figure 1.(a) MVC-NDVI Image of Jigawa State and Environs, (b) Extract Map of Jigawa State Local Government Areas, (c) Location of the study Area showing the sample sites for the study

2.3 Soil Samples Analysis

Sample soils taken from the different sampling sites were subjected to ECe and Textural class measurements since in remote sensing detection of salinity is based on the dielectric properties of the soil, because salinity is a key element of the electric conductivity (Aly et al., 2007). For soil EC measurement small stick conductivity meter was used in which 60g of dry soil from each of the sample soils were taken and mixed up with 300ml of distilled water in a Vegemite bottle, then shake for barely an hour and were then allowed to stand for 30 minutes. Electrode was then placed near the boundary of the water and settle soil. Digital readings was then taken in µS/cm (Table 1). For identifying the soil texture, a known amount of soil was picked by coning and rejection method (Abbasi et al, 2010) and placed in a measuring cylinder with addition of water. The contents was then stirred thoroughly and left undisturbed for twenty four hours (24hrs). The percentage of various soil particles, sand silt and clay were then measured converting the 'ml' of the measuring cylinder into percentage based on the textural triangle of USDA system for classification (Soil Survey Staff. 1993) (Table 1).

2.3.1 Satellite Data

In this study, monthly NDVI datasets derived from MODIS covering 2000, 2004, 2009 and 2010 for Jigawa State and Environs were recomposed into Maximum Value Composites (MVCs) a compositing technique adopted from Yelwa et al (2013) to reduce noise from the datasets. Maximum Value Compositing is commonly used for NDVI vegetation index imagery (Eastman, 2012). The datasets that comprises of 36 Monthly Mean datasets were reduced to 4 time series monthly Maximum Value Composites (MVCs) images (Figure 2). The four (4) monthly Maximum Value Composites (MVCs) images were reformatted using image windowing module to extract a subset of the study area- SuleTankarkar LGA (Figure 2).

Normalized Difference Vegetation Index (NDVI) is an index of plant 'greenness' or photosynthetic activity (The Landscape Tool box, 2011). Though, with application of appropriate techniques NDVI can also be used for other land cover studies. In this regard the study is virtually for detection of Holomorphic soil formation as one of the sub-type of Intra zonal soil. As such there is need to extract bare soil from the vegetative cover. Therefore, as according to Eastman (2012) identification of bare soil pixels on an NDVI image might be on NDVI values less than or equal to 0. This is when vegetation has higher reflectance in the infrared than in the red. Thus because of the "just less than" wording of the RECLASS module, you might assign the new value 1 to values from -1 to those just less than 0.000001 and the new value 0 from 0.000001 to just less than 1. This would include the value 0 in the bare soil category. And this serves the most effective way to generate soil mask image for the study of holomorphic soil formation using NDVI images (Figure 3).

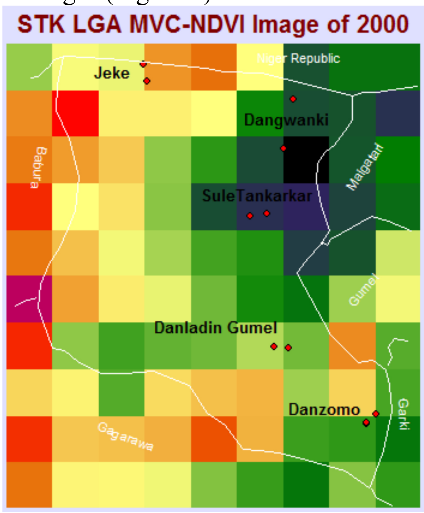


Figure 2: MVC-NDVI Image of 2000 used for the study

The soil spectral responses can be determined by the physical- chemical properties of the soils and the most important properties that influence the level of reflectance are: humus content, salinity, moisture, the structure of the arable horizon and content of carbonates, ferric hydroxides and gypsum (Karavanova, 1999). Soil Electrical Conductivity is a measure used to determine the spectral patterns of saline soils. And indeed significant quantity and minerology of the salts contained in the soils aids in the spectral response at the sensor field of view and thus facilitate to the sensitive changes of the EC and that accounts the reliable measure to detect holomorphic soil development (Figure 4). Thus Empirical Reflectance Method (ERM) used by Al- Khaier (2003) was adopted for the spectral extraction from the images. This has been achieved by the used of Hyperspectral signature extraction module.

Moreover Principal Components Analysis (PCA) which is a mathematical transformation based on the analysis of the covariance or the correlation of several spectral bands (Lhissou et al., 2014) was in cooperated into the study and offer a precise and impressive approach in detecting Holomorphic soil formation with Standardized Principal Components (Figure 4). The whole image transformation and analysis was carried within the Idrisi Selva software.

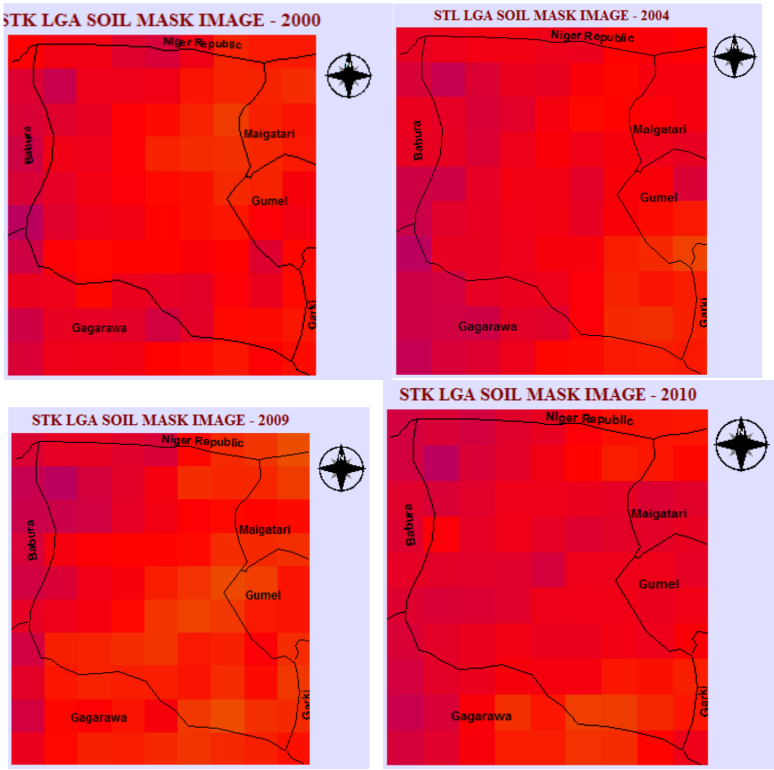


Figure 3: Soil mask images of the study area derived from NDVI image of 2000, 2004, 2009 and 2010

3. Results And Discussion

The results obtained for this study is to understand the spatial development of Holomorphic soil in an area being characterized with infrequent rainfall lasting for four to five months thus soluble salts are more likely to accumulate and remain near the soil surface.

Table 1: Soil Analysis

S/N	Sample I.D	%Clay	%Silt	%Sands	Textural class	EC (µS/cm)
1	Danladi site 1	11.2	6.56	82.24	Loamy sand	8.22
2	Danladi site 2	*11.2*	8.56	80.24	Sandy loam	16.73
3	Dangwanki site 1	9.2	4.4	86.4	Loamy sand	13.66
4	Dangwanki site 2	9.2	0.56	90.24	Sand	19.46
5	Danzomo site 1	11.2	8.56	80.24	Sandy loam	63.7
6	Danzomo site 2	9.2	10.56	80.24	Loamy sand	27.9
7	Jake site 1	5.76	4	90.24	Sand	17
8	Jake site 2	9.2	0.56	90.24	Sand	11.22
9	SuleTankarkar site 1	17.2	8.56	74.24	Sandy loam	32.3
10	SuleTankarkar site 2	9.2	4.56	86.24	Loamy sand	12.02

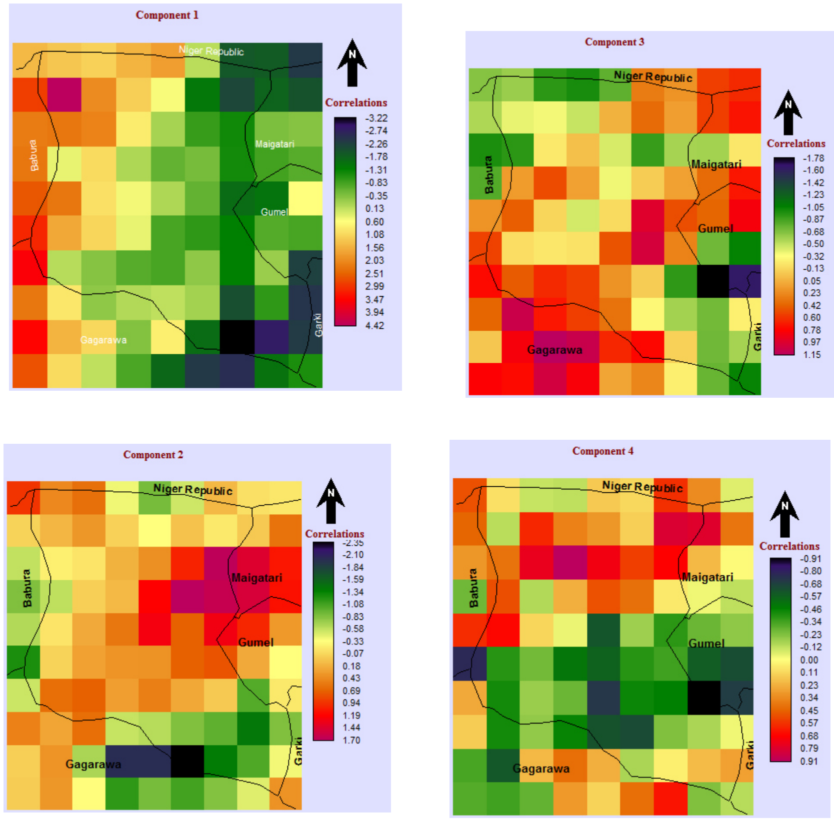
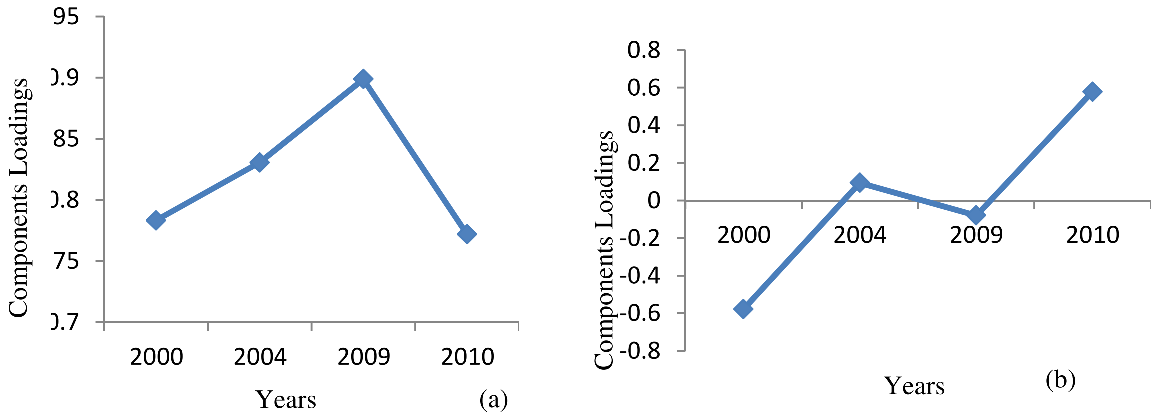
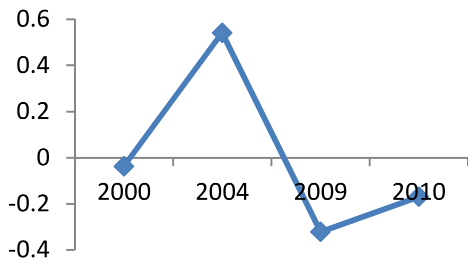


Figure 4: Components Images derived from PCA using Standardized principal components





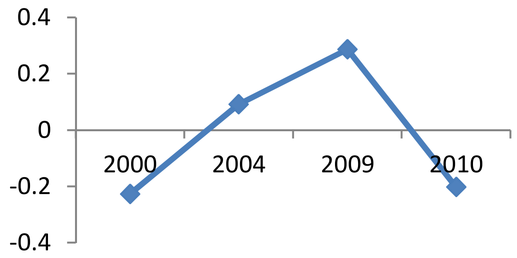


Figure 5: Graphs showing components loadings from the PCA components using standardized principal components

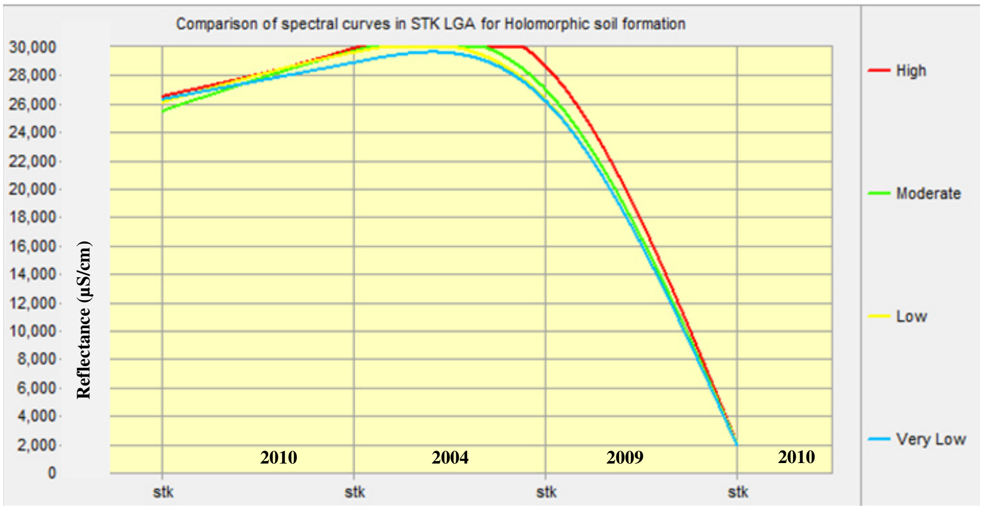


Figure 6: Hyperspectral reflectance of Holomorphic soil in different Years

Table 1 show the physicochemical analysis carried on textural classes and the electrical conductivity (EC) of the soil in the study area. This provides the basis to establish a link to the spectral reflectance measurement on the satellite images. The soil texture is to determine the proportion of different particle size components of the soil samples and viewed as one of the determinant factor for reflectance measurements. Thus reflectance values shows a decreasing trend with heavier soil texture (sandy and loam > clayey) (Gotterbarn et al., 2016). The analysis revealed that much of the soils in the sample sites are sandy, the texture ranging from sandy to very fine sandy loam. The fine sandy fractions dominate the soils and this can be as a result of Aeolian deposits (Maduakor, 1991.). So the surface texture of the sample sites is being predominated by sand, loamy sand and sandy loam, FAO (2001) classified these textural classes of the soil in the area into Aresonol and Fluvisol soils.

Electrical Conductivity (EC) is a measure of the amount of salts in the soil (USDA, 2014) measured in either MilliSiemens per meter (mS/m), deciSiemens per meter (dS/m) or with micro Siemens per centimeter (µS/cm) and most of the conductivity meters give readings in micro Siemens per cm (µS/cm). The Electrical Conductivity of the saturated soil Extract (ECe) measurement was carried out in a laboratory which the results (Table 1) obtained shows that Danladi site 1 has the lowest values – 8.22µS/cm and Danzomo site 1 with highest values - 63.7µS/cm. This indicates that the potentiality of detecting the formation of Holomorphic soil is very low in the sample sites. The amount required to determine the existence of the soil is when EC readings is greater than 1 dS/m or 1000µS/cm. Therefore when such amount has been obtained the soil has reached a salinization level and would be classified as Holomorphic. In its determination we noticed that there were a high proportion of sands over that of silts and clay particles (Table 1) in which EC correlates strongly to soil particle size and texture. Thus Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity (Robert et al., 2009). In detecting Holomorphic soil virtually the proportion of clay and silts particles would be higher than sands and from this findings both the clay and silt particles have less than 18% respectively indicating a very insignificant amount for its formation.

Figure 3 shows the soil mask images of the study area which derived from the NDVI images (Figure 2) for this study. It is on these images that we applied empirical reflectance method to determine the formation of Holomorphic soil based on the spectral reflectance patterns. The data used were in hyperspectral format largely relies upon the use of a library of spectral curves associated with specific earth surface materials (Eastman, 2012). For this study hyperspectral signature files were created to generate the spectral response of the soil type which ranges from zero to thirty micro centimeters (0- 30,000µS/cm) with a signature name – high, moderate, low and very low (Figure 6). Since hyperspectral remote sensing is only able to measure the reflectance of the first few millimetres of the surface (Grandjean et al., 2009). Therefore from the spectral curves of the Holomorphic soil formation it shows that there were significant maximum increases of its formation from 2000 to 2009 and relatively decreases to very low values in 2010. This can be correlated to laboratory findings where the soil EC values recorded after 2010 from the different sample sites were below the determination level for holomorphic formation. This can be essentially linked to the movement of water that control salt transport. In fact changes in the pattern of rainfall as the result of its increases in the time- period may slow down the rate of carrying dissolved salts to the surfaces.

Figure 4 and 5 are components images and graphs derived from Principal Component Analysis (PCA) using standardized principal components for time –series analysis of the Holomorphic soil formation. The four component images (Fig.4) and the loading graphs (Fig.5) showed that the area under study SuleTankarkar was affected with the formation that is from year 2000 to 2009 covering to about 65% of the area. But from the graph loadings (Fig,5a) shows that there were an abrupt decrease of the formation from 2009 to 2010 and this has a correlation with our physicochemical findings - the soil EC readings (table 1) and the spectral curves of the formation. While the subsequent component images (2, 3 and 4) showed little amount of changes, though there were pockets of occurrences in the time period.

4. Conclusion

NDVI is useful for assessing the health and density of vegetation (GLCF, 2014) but can also be used to assess other land cover changes with appropriate techniques. Since NDVI is a ratio of the red and near infrared reflectance. This study utilizes the data sets and proved effective in detecting spatial Holomorphic soil formation from the imageries. The physicochemical analysis of the field data opened the basis of the spatial variability of the formation. Empirical reflectance method serves as a good auxiliary variable for the spatial understanding of the time-series of the formation. The Principal Component Analysis (PCA) using standardized principal components allowed finding the most correlated parameters with the soil formation.

5. Recommendations

Holomorphic soil formation is one of the most important aspects of soil degradation. The formation of this soil may basically induced changes in agricultural suitability, in declining rate of productivity and in some cases in relation to its biotic functions. Remote sensing however has the ability to obtain imagery of soil degraded areas at regular intervals over many years in order that changes in the landscape can be evaluated.

Changes in agricultural suitability can be overcome through constant application of manure in areas where the soil contained an element of salts. And there is need to closely monitor the high use of nitrogen fertilizer contains high amount of soluble salts. Also for effective utilization of soil nutrient management shall be induced such like application of manures, compost can aid in its deterioration.

Acknowledgements

The authors principally wish to acknowledge TETFUND Abuja, Nigeria who financially supported this work. We gratefully acknowledge National Aeronautics and Space Administration (NASA) who supplied the NDVI data sets through Najijima Environmental Consultants for the study. We also acknowledge the District Heads for their assistance rendered during the field works.

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