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Estimation of Soil Moisture Content in Oredo Local Government Area of Edo-State Using Remote Sensing Technique: 2017 Study

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Abstract

Soil moisture estimation is essential for optimal water and soil resource management. Surface soil moisture is an important variable in the natural water cycle, which plays an important role in the global equilibrium of water and energy due to its impact on hydrological, ecological and meteorological processes. Soil moisture changes due to the variability of soil characteristics, topography, and vegetation in time and place and affects vegetation distribution. Too little moisture can result in yield loss and plant death and too much causes root disease and wasted water. Soil moisture measurements are performed directly using in situ methods and indirectly, using transfer functions or remote sensing. Since in-situ measurements are usually costly and time-consuming in large areas, we can use methods such as remote sensing to estimate soil moisture at very large scales. The purpose of this study is to estimate soil moisture using land surface temperature. In this work, ground temperature was calculated using Landsat-8 thermal infrared band for Oredo Local Government Area and was used to estimate the soil moisture of the study area using ArcGIS (Arc-map 10.2.2). The study revealed places with low, moderate and high moisture contents with the moderate moisture index being dominant in both seasons. This study will thus serve as a database that will enable farmers to embark on precision farming with the local government area under investigation.

1.0. Introduction

Soil moisture is the total amount of water present in the upper 10 cm of soil and it represents the water on the land surface that resides in the pores of the soil which is not in rivers, lakes, or groundwater and which depends on the weather conditions, soil type, and associated vegetation, among others. Soil moisture assessments are important to understand the hydrological cycles and biophysical processes caused by global climate changes [1]. Usually, soil moisture has been mapped with airborne microwave radiometers [2] to measure the water retained in the spaces between soil particles. Its importance is due to the microorganism metabolic activity, regulation of the soil temperature, and carriage of nutrients, among others. Soil moisture typically takes the form of small ice crystals, vapor, or small parts of liquid water in cold desert soils [3]

Soil moisture is a very fundamental component in hydrology, climate and soil vegetation interaction. Hence, soil moisture estimation helps in many natural resource applications such as hydrological modeling, stream flow and flood and drought mapping and monitoring. Several authors have revealed the importance of soil moisture estimation for drought monitoring [4].

Precise soil moisture is a key factor in these studies. Remote sensing techniques for soil moisture estimation include the use of visible, thermal infrared and active/passive microwave data so that each has its own advantage and disadvantage. However, still, optical remote sensing is an effective technique for estimating soil moisture. This method requires the estimation of surface temperature and vegetation index for soil moisture calculation [5].

[6] worked on Quantifying Land-use cover Oredo L.G.A, Edo-State. Satellite images from Landsat. ERDAS imagine 2014, ENVI 5.0, and ArcGIS 10.2.2 were used and the result showed that, while forest and water bodies decreased, the other land uses such as settlements increased over the same period.

2. Methodology

2.1. Study Area

The study was carried out in the Oredo local government area of Edo-state of Nigeria.
Oredo has an area of 237.4 square km, which lies between longitude 5 2°'00" E and 5 18°'30" E and latitude 6 18°'30" N and 6°31'00" N. Oredo is bounded in the north by Egor LGA; west by Ovia North-East LGA; south and east by Ikpob -Okha LGA.
The Oredo area has a tropical savanna climate and has a population of over 1,125,058 people.

Figure 1. Map of Edo State with Oredo Local Government Area indicated in red rectangle. [7].

2.2. Data Collection

The work on Oredo Local Government Area was carried out using Landsat-8 satellite data from the United States Geological Survey (USGS) and downloaded using the google earth engine and analyzed using ArcGIS software 10.2.2. The LST of the study area for all the seasons was gotten using a java-script within the google earth engine from which the SMI was calculated.

In this study, Bands 4 and 5 of the infrared Spectrum were utilized to calculate the NDVI, whereas bands 10 were used to estimate brightness temperature. The USGS website for extracting top of atmospheric (TOA) spectral radiation was used as the source for the LST retrieval formulas. Following the procedures in Figure 2, the LST was retrieved.

Figure 2 presents the flowchart of this research. It illustrates different processing steps to achieve the soil moisture map.

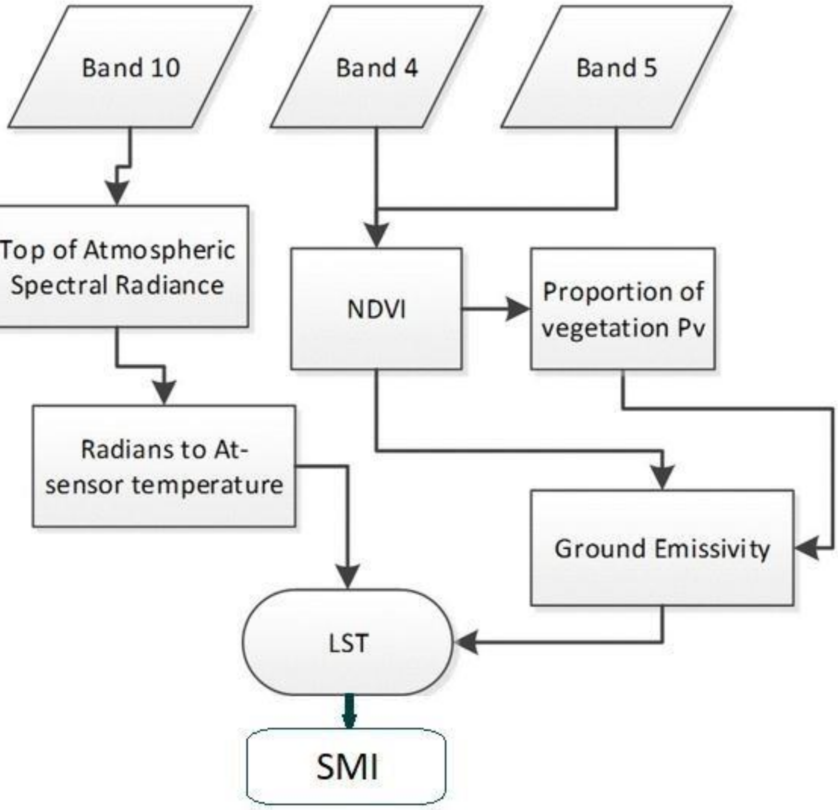

Fig. 2. Flowchart for SMI calculation (modified after Kaplan and Gordana, 2018)

2.3. Conversion of Digital Numbers (DN) to Top of Atmospheric Spectral Radiance: DN, the thermal band data was converted to TOA spectral radiance using the rescaling radiance factors from the metadata file of the satellite image. [8]

$L_\lambda = M_L Q_{cal} + A_L$ 1

Where;

L_λ= TOA spectral radiance (Watt/(m^2*srad*μm))

M_L = Band-specific multiplicative rescaling factor from the metadata

Q_{cal} = Standard product pixel values

A_L=Band-specific additive rescaling factor

2.4. Conversion of TOA to Atmospheric Satellite Brightness Temperature: Utilizing the thermal constants in the MTL file, thermal band data can be converted from spectral radiance to top of atmospheric brightness temperature. [8]

$$BT = \frac{K_2}{In\left[\left(\frac{K_1}{L_\lambda}\right)+1\right]} - 273.15 \quad 2$$

Where;

BT = Top of atmosphere brightness temperature K

L_λ= TOA spectral radiance ($Watt/(m^2 * srad * \mu m)$)

K_1 = Specific band conversion constants from metadata

K_2 = Specific band conversion constants from metadata

2.5. Calculating NDVI: The Normalized Difference Vegetation Index (NDVI), associated with drought conditions. Bands 4 and 5 respectively were used to calculate the NDVI. Since the amount of vegetation present is a crucial element and the NDVI can be used to estimate general vegetation status, calculating the NDVI is crucial. [9]

$$\mathrm{NDVI} = \frac{\mathrm{NIR(band\ 5)} - \mathrm{R(band\ 4)}}{\mathrm{NIR(band\ 5)} + \mathrm{R(band\ 4)}} \qquad 3$$

Where;
NIR (Near Infrared) = Band 5
R (Red) = Band 4

2.6. Calculating the Proportion of Vegetation: The percentage of ground covered by vegetation in a vertical projection is referred to as the vegetation fraction (proportion of vegetation). The NDVI values for vegetation and soil are strongly connected to the percentage of vegetation (P_v). P_v was calculated in this study using the conventional NDVI approach. [9]

$$P_v = [\frac{\mathrm{NDVI} - \mathrm{NDVI_{min}}}{\mathrm{NDVI_{max}} - \mathrm{NDVI_{min}}}]^2 \qquad 4$$

Where, $\mathrm{NDVI_{min}}$ is the minimum
$\mathrm{NDVI_{max}}$ is the maximum

2.7. Calculating Land Surface Emissivity: The Land Surface Emissivity can be calculated from the Proportion of Vegetation thus. [10]

$$\mathcal{E} = 0.004P_v + 0.986 \qquad 5$$

Calculating Land Surface Temperature: LST can be computed thus;

$$\mathrm{LST} = \frac{\mathrm{BT}}{1 + \left[\left(\frac{\lambda \mathrm{BT}}{\rho}\right)\right] \mathrm{In}\, \mathcal{E}} \qquad 6$$

Where;
BT represents Top of Atmosphere Brightness temperature
λ represents the wavelength of emitted radiance
$\mathcal{E}$ is the emissivity
ρ=hc σ = 1.438 x 10^{-2} m. K
where σ is the Boltzmann constant (1.38 × 10^{-23} J/K), *h* is Planck's constant (6.626 × 10^{-34} J s), and *c* is the velocity of light (2.998 × 10^8 m/s).

2.8. Calculating Soil Moisture Index: The Soil Moisture can be calculated from the LST using the formula;

$$\mathrm{SMI} = \frac{\mathrm{LST_{max}} - \mathrm{LST}}{\mathrm{LST_{max}} - \mathrm{LST_{min}}} \qquad 7$$

Table 1. Metadata for the year, 2017.

YEAR(2017)	SENSOR ID	RESOLUTION(m)	SENSING TIME/DATE	CLOUD COVER	LOCATION
JAN-MAR.	OLI&TIRS	30	2017/03/25 T09:56:22.5245570Z	30	OREDO
APR-SEPT.	OLI&TIRS	30	2017/09/30 T09:56:40.4367740Z	35	OREDO
OCT-DEC.	OLI&TIRS	30	2017/12/22 T09:56:57.4775545Z	30	OREDO

3. Results and Discussion

The soil moisture index (SMI) which is a measure of the soil moisture is an index ranging between 0 and 1 with 0 indicating very dry conditions with extremely low moisture content and 1, wet conditions with high moisture content. In the maps, the results are presented in three different colors. The yellow color has 0 - 0.3 moisture index value indicating low moisture content, the blue color has 0.3 - 0.6 moisture index value indicating moderate moisture content and the green color has 0.6 – 1 representing high moisture content.

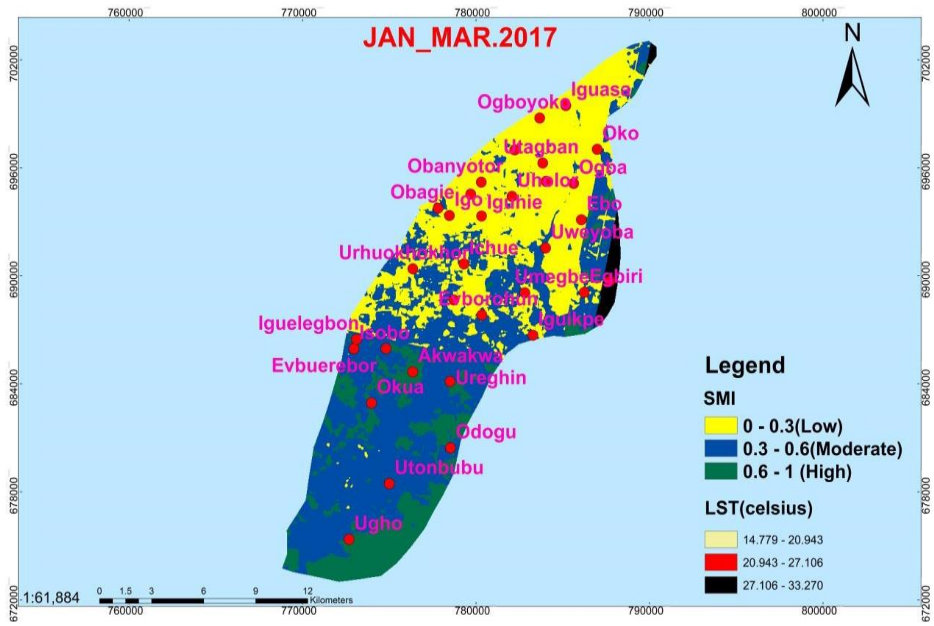

Figure 3: Soil moisture index map for 2017 dry season

The moisture index for Jan. to Mar. 2017, showed that a low moisture index class was observed in the northern region of the study area especially places like Iguasa, Ogboyoko, Utagban, and Oko among others. The moderate moisture index class occurs all over the study area such as Utonbubu, Okua, and Iguelegbon fall within this class. The high moisture index occurs within the southern and eastern parts of the study area. Areas as Ugho, Odogu, and Ureghin fall in this class. The low moisture index covers 37.66%, the moderate moisture index covers 45.98%, the high moisture index covers 14.64%, and 1.72% of the area was distorted by cloud cover. The moderate moisture index class is the most dominant. The mean moisture index is 0.40, the standard deviation is 0.17.

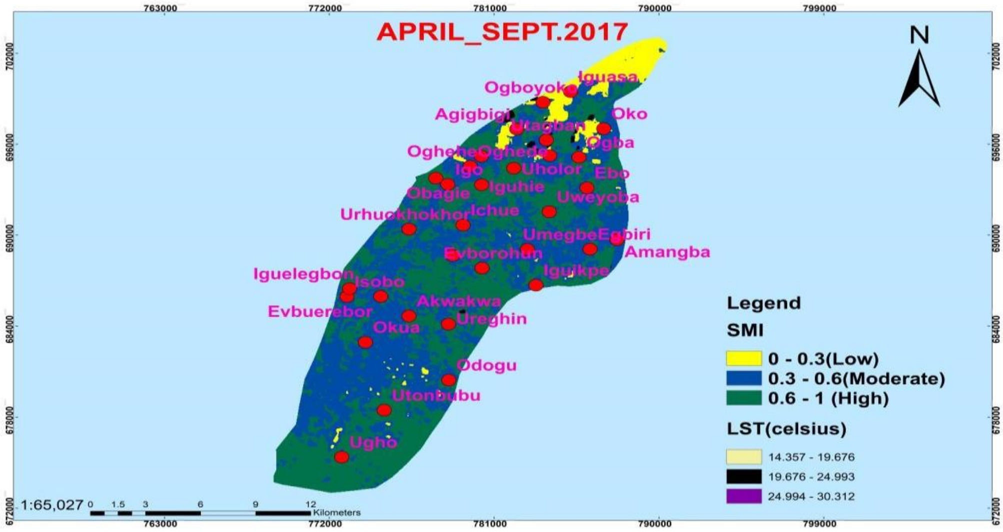

Figure 4: Soil moisture index map for 2017 wet season

The moisture index for April to Sept.2017, showed that a low moisture index class was observed in the northern region of the study area especially places like Iguasa, Ogboyoko, Utagban, and Oko. The moderate moisture index class occurs all over the study area such as Ogba, Okua, and Ichue fall within this class. The high moisture index occurs within the southern and eastern parts of the study area. Areas such as Ugho, Odogu, Ureghin, Uholor, Igo, and Utonbubu fall in this class. The low moisture index covers 6.29%, the moderate moisture index covers 42.19%, the high moisture index covers 51.0%, and 0.5% of the area was distorted by cloud cover. The high moisture index class are the most dominant. The mean moisture index is 0.47, the standard deviation is 0.09.

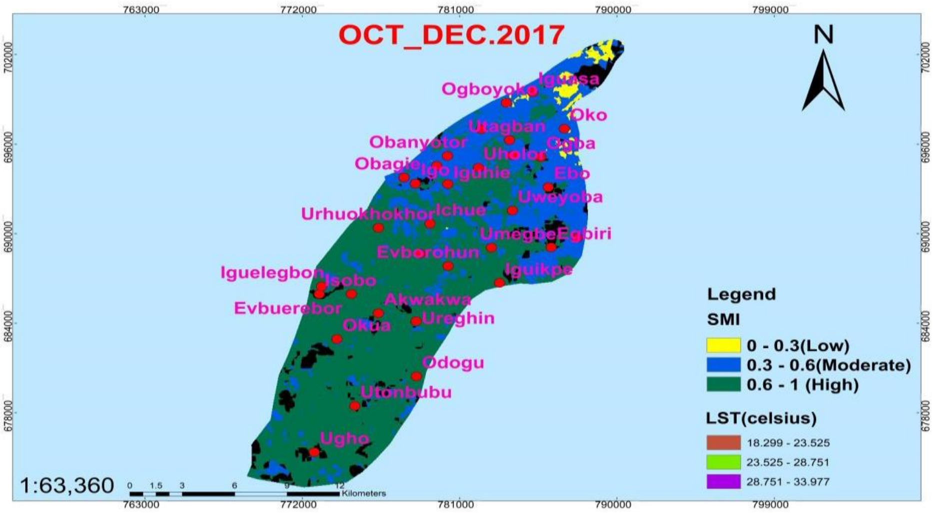

Figure 5: Soil moisture index map for 2017 dry season

The moisture index for Oct. to Dec.2017, showed that a low moisture index class was observed in the northern region of the study area especially places like Iguasa, Ogboyoko. The moderate moisture index class occurs all over the study area such as Ogba, Utagban, Oghehe, Oghede, and Igo fall within this class. high moisture index occurs within the southern and eastern parts of the study area. Areas such as Ugho, Odogu, Ureghin, Uholor, Utonbubu, and Okua fall in this class. The low moisture index covers 1.63%, the moderate moisture index covers 28.81%, the high moisture index covers 63.61%, while 6% of the area was distorted by cloud cover. The high moisture index class is the most dominant class. The mean moisture index is 0.42, the standard deviation is 0.17.

Table 2. The mean soil moisture index, 2017

MEAN SOIL MOISTURE INDEX, 2017	
WET SEASON	**DRY SEASON**
0.47	**0.41**

Table 3. Percentage of soil moisture index 2017, distribution in Oredo LGA Benin City.

	DRY SEASON			**WET SEASON**		
YEAR	**HIGH(%)**	**MODERATE(%)**	**LOW(%)**	**HIGH(%)**	**MODERATE(%)**	**LOW(%)**
2017	39.13	37.40	19.65	51.00	42.19	6.29

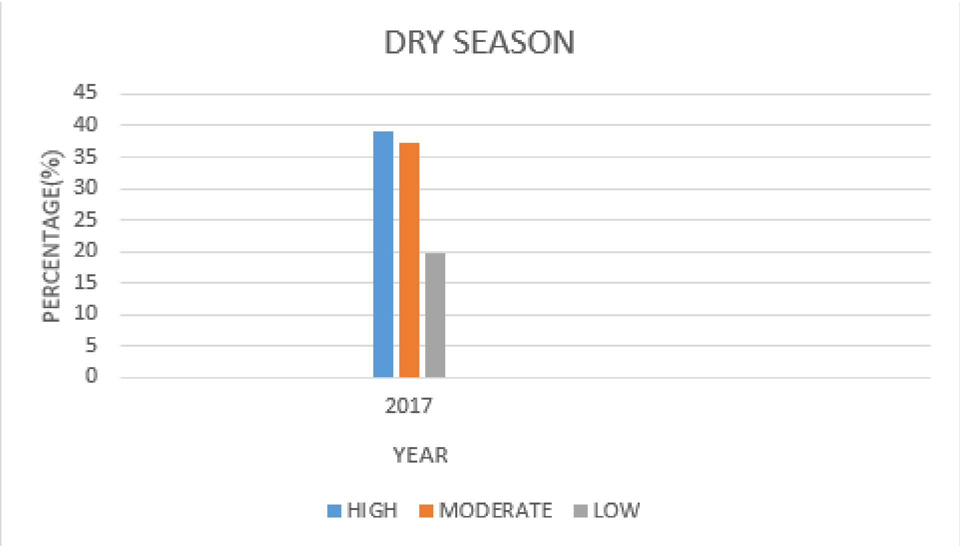

Figure 6: Bar Chart showing the percentage of soil moisture index.

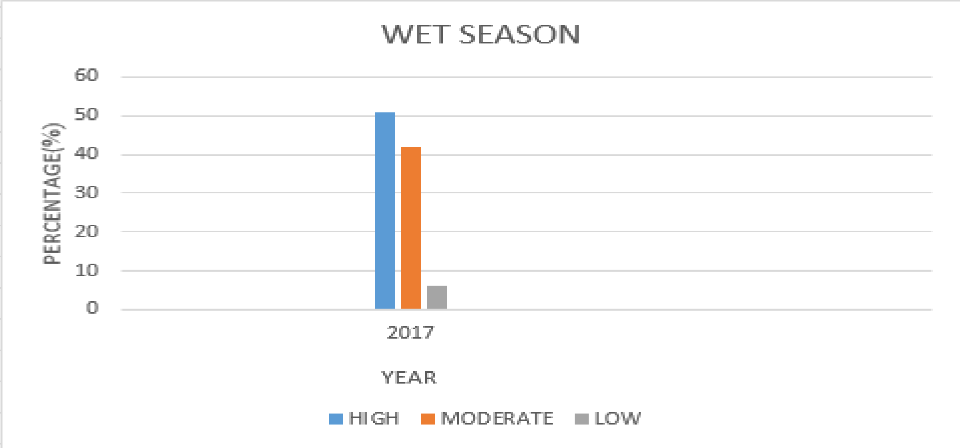

Figure 7: Bar Chart showing the percentage of soil moisture index.

4. Conclusion

In this research, a prediction soil moisture model has been applied to Oredo Local Government Area which demonstrates the power of remotely sensed data. This model can be applied without the need to move to the area of interest to predict soil moisture in an environmentally sustainable way with minimum economical costs to easily analyze large areas. The soil moisture map obtained by this model is able to show good soil moisture variation within the studied area.

Conflict of Interest

There is no conflict of interest associated with this work.

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