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Remote Sensing Application in Soil Moisture Content Estimation

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Abstract

The knowledge of soil moisture is crucial to agriculture and other sectors such as, the construction industries. Precise estimation of spatial and temporal variation of soil moisture is vital for ecological and hydrological studies also. In recent times, remote sensing techniques have been used to estimate soil moisture. Estimation of soil moisture by remote sensing techniques provides only surface layer information and is unable to observe the entire soil. However, on the other hand, field measurement provides valuable information on both surface and subsurface soil moisture, but are insufficient to determine the spatial and temporal variability of soil moisture at a larger scale. Therefore, remote sensing methods have an edge over field methods. Soil moisture variations in time and space are due to the vegetation, topography and soil texture. This paper presents a comprehensive work in estimating soil moisture using Land surface temperature. The temperature was gotten using Landsat-8 thermal infrared band for Oredo Local Government Area and was used to determine the soil moisture of the area using ArcGIS (ArcMap 10.2.2).The map showed places with low, moderate and high moisture index with the moderate moisture content being the most dominant.

1. Introduction

Soil moisture has a vital implication for agriculture, ecology, wildlife and a crucial variable in Land surface hydrology. Soil moisture can be defined as the water in the unsaturated part of the soil profile [1]. Soil moisture data is necessary for parameterizing numerical models, which are used to determine evapo-transpiration from land cover, deep percolation for groundwater impact studies as well as water resource management, for meteorological and agricultural application [2].

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. Soil moisture in the upper part of the earth’s surface is recognized as a key variable in numerous environmental studies including meteorology, hydrology, agriculture and climate change [3,4,5,6,7,8,9]. Therefore, it is imperative to monitor and estimate accuracy of the spatial and temporal variations of soil moisture.Development in remote sensing satellite technology has offered a number of techniques for determining soil moisture across a wide area continuously over time [10]. Many researchers have shown that surface soil moisture content can be measured by optical and thermal infrared remote sensing, as well as passive and active microwave remote sensing techniques [11]. The primary difference among these techniques are the wavelength region of the electromagnetic spectrum used, the source of the electromagnetic energy [12], the response measured by the sensor and the physical relationship between the response and the soil moisture content [13].

Numerous studies have shown the influence of soil moisture on the feedbacks between land surface and climate that has a profound influence on the dynamics of the atmospheric boundary layer and a direct relationship to weather and global climate [14,15,16,17]. [18] have shown the influence of spatial variations of soil moisture and vegetation on the development and intensity of severe storms. [19] demonstrated the ability of soil moisture to influence surface moisture gradients and to partition incoming radioactive energy into sensible and latent heat in large scale modeling.

The soil moisture and surface temperature are key variables in deciding the depth of the planetary boundary and circulation and wind patterns [20,21,22]. Satellite remote sensing enable us to estimate large scale soil moisture for the purpose of modeling the interactions between land atmosphere, helping us to model weather and climate with higher accuracy. Hence, this paper investigates the soil moisture content of Oredo Local Government Area, using remote sensing application.

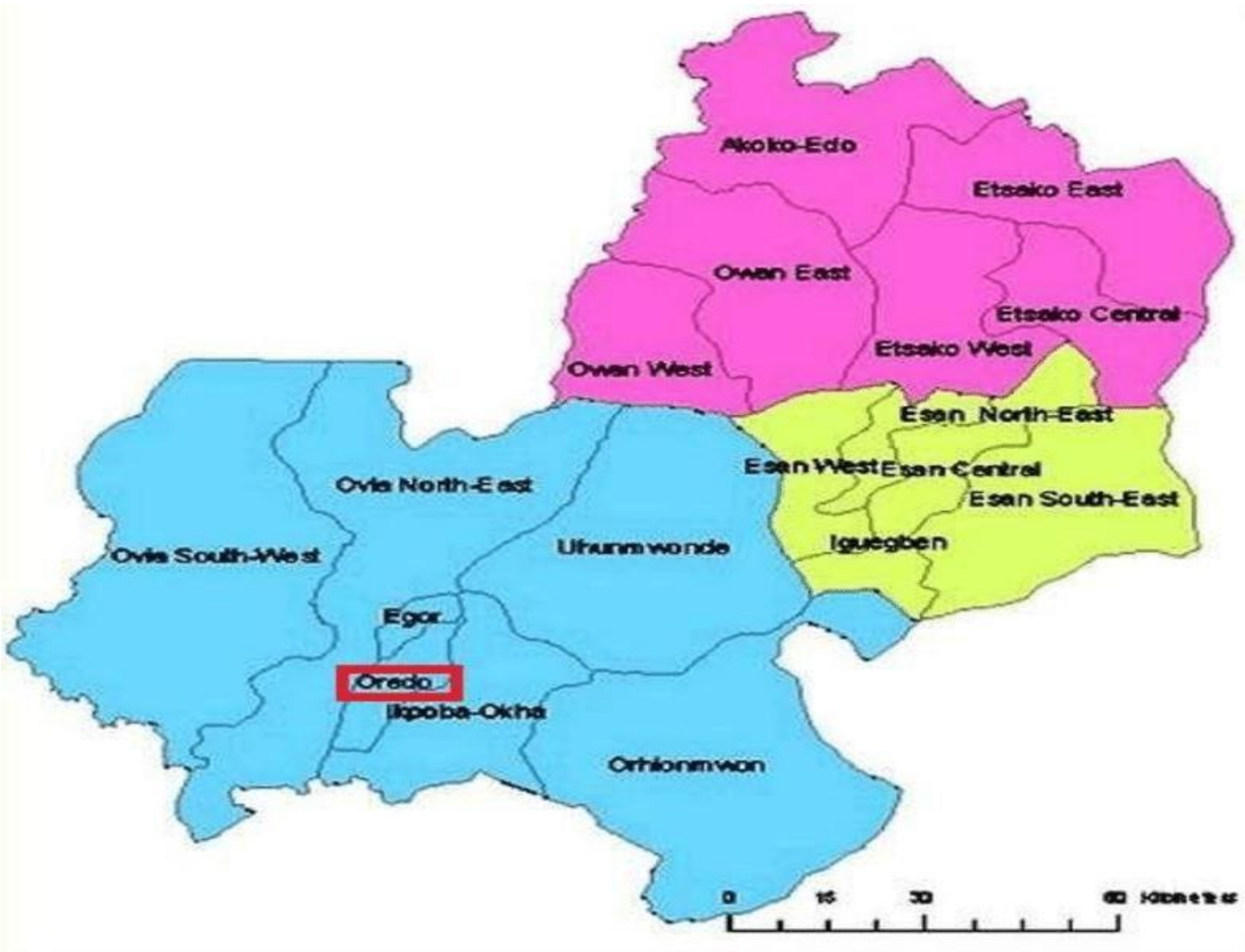

Figure1 Map of Edo State with Oredo Local Government Area indicated in red rectangle. [23]

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 2̊'00" E and5 18̊'30" E and latitude 6 18̊'30" N and 6̊31'00" 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.

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.

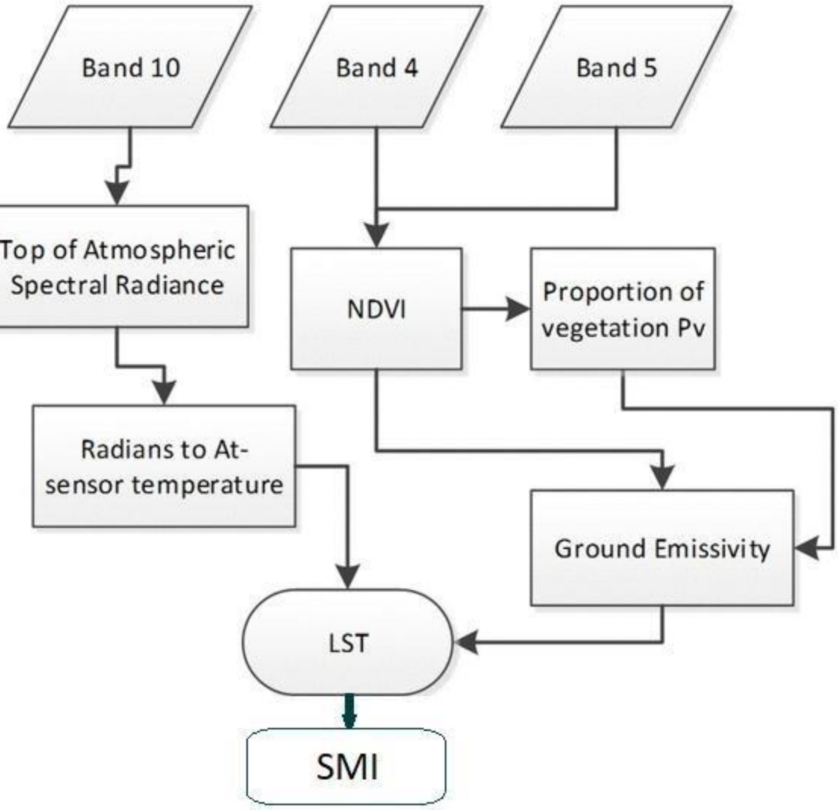

Fig. 2. Flowchart for SMI calculation (modified after Kaplan and Gordana, 2018)

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. [24]

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

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 [24]

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

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. [25]

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

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). (Aman et al., 1992; Twumasi et al., 2021). 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 [25].

$$P_v = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right]^2 \quad (4)$$

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

2.7. Calculating Land Surface Emissivity:
The Land Surface Emissivity can be calculated from the Proportion of Vegetation thus [26]
$\mathcal{E} = 0.004 P_v + 0.986$ (5)

Calculating Land Surface Temperature: LST can be computed thus;

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

Where;
BT represents Top of Atmosphere Brightness temperature
λ represents the wavelength of emitted radiance
$\mathcal{E}$ is the emissivity

$\rho = hc\sigma = 1.438 \times 10^{-2}$ 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;

$$SMI = \frac{LST_{max} - LST}{LST_{max} - LST_{min}} \quad (7)$$

Table 1. Metadata for the year, 2020.

YEAR(2020)	SENSOR ID	RESOLUTION(m)	SENSING TIME/DATE	CLOUD COVER	LOCATION
JAN-MAR.	OLI&TIRS	30	2020/03/26 T09:50:43.9642570Z	25	OREDO
APR-SEPT.	OLI&TIRS	30	2020/09/24 T09:57:15.1019450Z	35	OREDO
OCT-DEC.	OLI&TIRS	30	2020/12/30 T09:57:26.8477679Z	30	OREDO

Source: Google Earth Engine

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 has0 - 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.

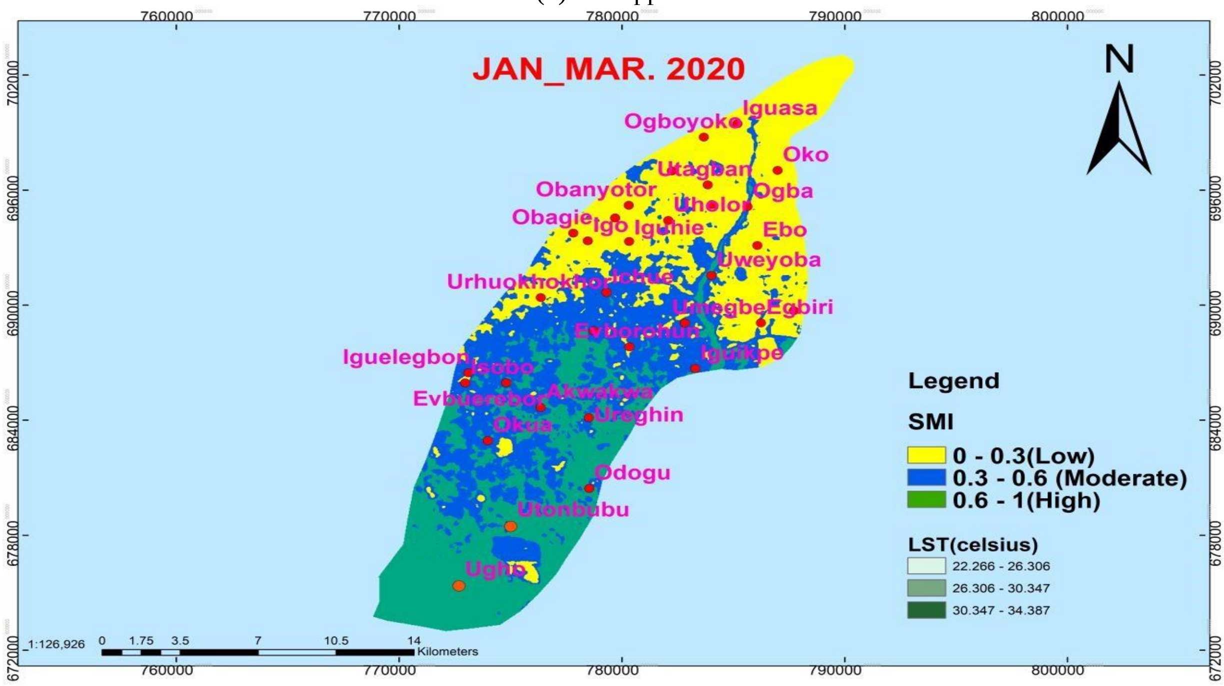

Figure 3: Soil moisture index map for 2020 dry season.

The moisture index for Jan. to Mar.2020, showed that a low moisture index class was observed in the northern region of the study area especially places like Iguasa, Ogboyoko, Oko, Obagie and Igo. The moderate moisture index class occurs all over the study area such as Iguikpe, Umegbe, 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, Utonbubu, fall in this class. The low moisture index covers 25.8%, the moderate moisture index covers 55.8%, and the high moisture index covers 18.4%. The moderate moisture index class is the most dominant. The mean moisture index is 0.49, the standard deviation is 0.19.

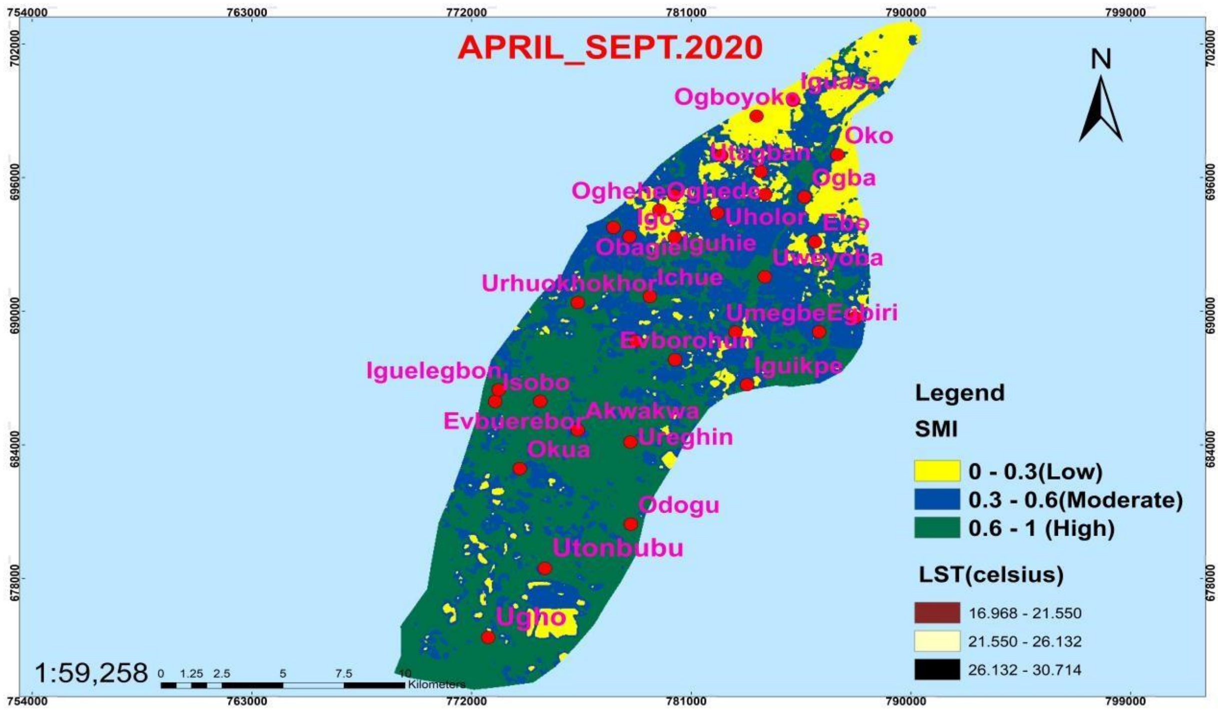

Figure 4: Soil moisture index map for 2020 wet season

The moisture index for April to September 2020, showed that a low moisture index class was observed in the northern region of the study area especially places like Iguasa, Ogboyoko, Oko, and Igo. The moderate moisture index class occurs all over the study area such as Ogba, Utagban, and Obagie 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, Utonbubu, and Okua fall in this class. The low moisture index covers 14.0%, the moderate moisture index covers 37.0%, and the high moisture index covers 49%. The high moisture index class is the most dominant. The mean moisture index is 0.44, the standard deviation is 0.12.

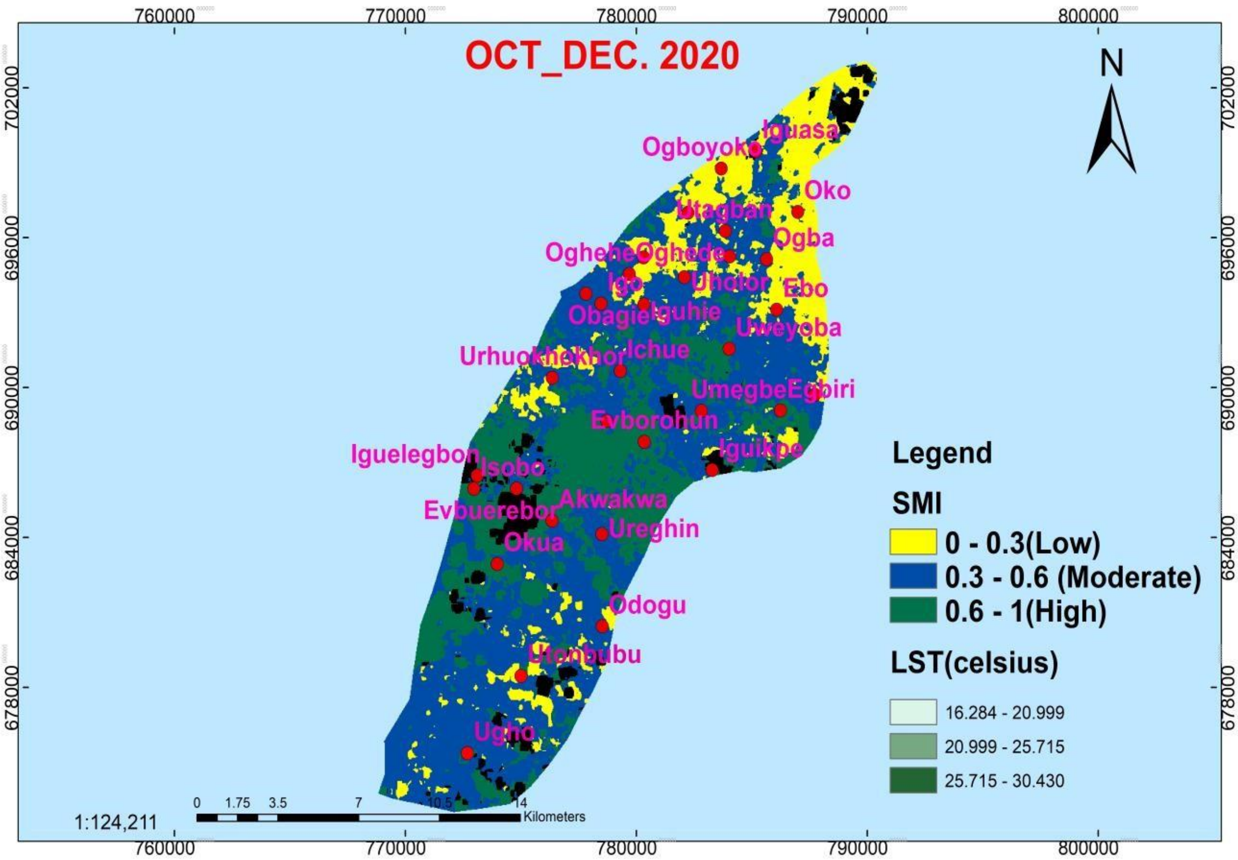

Figure 5: Soil moisture index map for 2020 dry season

The moisture index for Oct. to Dec.2020, showed that a low moisture index class was observed in the northern region of the study area especially places like Iguasa, Ogboyoko, Obanyotor, and Oko. The moderate moisture index class occurs all over the study area such as Ogba, Obagie, Igo fall within this class. The high moisture index occurs within the southern and eastern parts of the study area. Areas such as Ugho, Akwakwa, and Okua fall in this class. The low moisture index covers 9.8%, the moderate moisture index covers 80.8%, the high moisture index covers 6.2%, and 3.1% of the land area was distorted by cloud cover. The moderate moisture index class is the most dominant. The mean moisture index is 0.48, the standard deviation is 0.11.

Table 2. Percentage of soil moisture index 2020, distribution in Oredo LGA Benin City.

	DRY SEASON			WET SEASON		
YEAR	**HIGH(%)**	**MODERATE(%)**	**LOW(%)**	**HIGH(%)**	**MODERATE(%)**	**LOW(%)**
2020	**12.30**	**68.30**	**17.80**	**49.0**	**37.0**	**14.0**

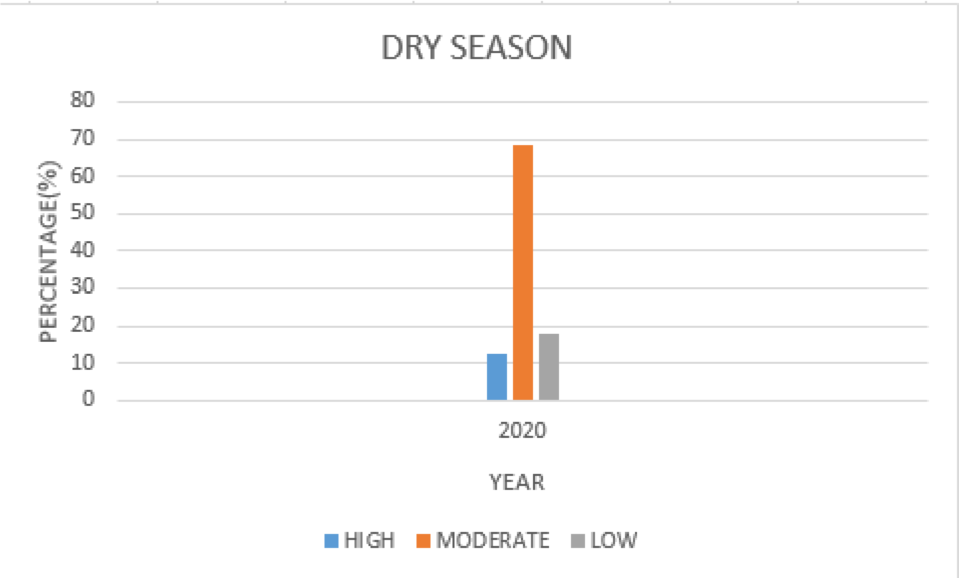

Figure 6: Bar Chart showing the percentage of soil moisture index.

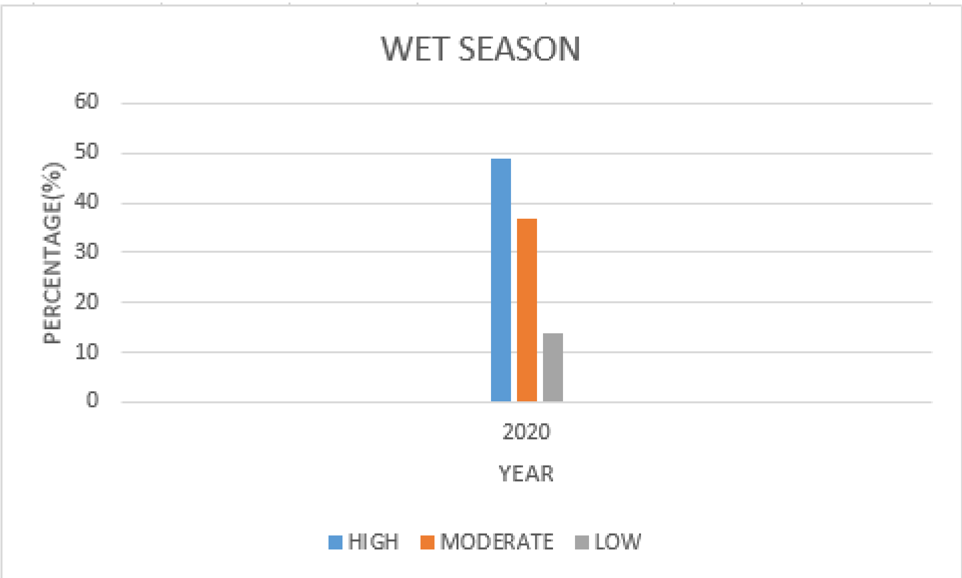

Figure 7: Bar Chart showing the percentage of soil moisture index.

4. Conclusion

In this research, a prediction of 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 was able to show good soil moisture variation within the studied area.

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