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The Use of Remote Sensing Technique in Mapping Possible Flood Prone Areas within Oredo Local Government Area of Edo State, Nigeria

Mike O. Ikponmwen and Cosmas C. Oyibo*
Department of Physics, University of Benin, Benin City, Edo-State, Nigeria.
*Corresponding Author Email:cosmasehike@gmail.com

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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. Too little or very high soil moisture can be an indication of a disequilibrium in the water recharge and discharge cycle, which may be indicative of potential flooding or draught respectively. 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. 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). Object base modeling was used in the classification of the study area into area of high, moderate and low moisture content for both the rainy and dry seasons respectively. This study is expected to serve as a database that can be built upon by relevant government agencies to enable them embark on proper town planning and flood management strategy within the local government area under investigation

1. 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]
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.[7] carried out a research titled “Evaluation of the extent of land-use cover changes in Benin-City using Landsat8 satellite data and ENVI 5.2 software and ArcGIS. The result showed that 284.56 km^2 of forest lands were lost over 32 years and built-up areas increased by 153.96 km3 over the same period. The present study aimed to provide soil moisture estimation model using NDVI and LST datasets for Oredo Local Government Area, Edo-State with a few to integrating it into any flood management plan within the study area.

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 and5 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 Ikpoba -Okha LGA.
The Oredo area has a tropical savanna climate and has a population of over 1,125,058 people.

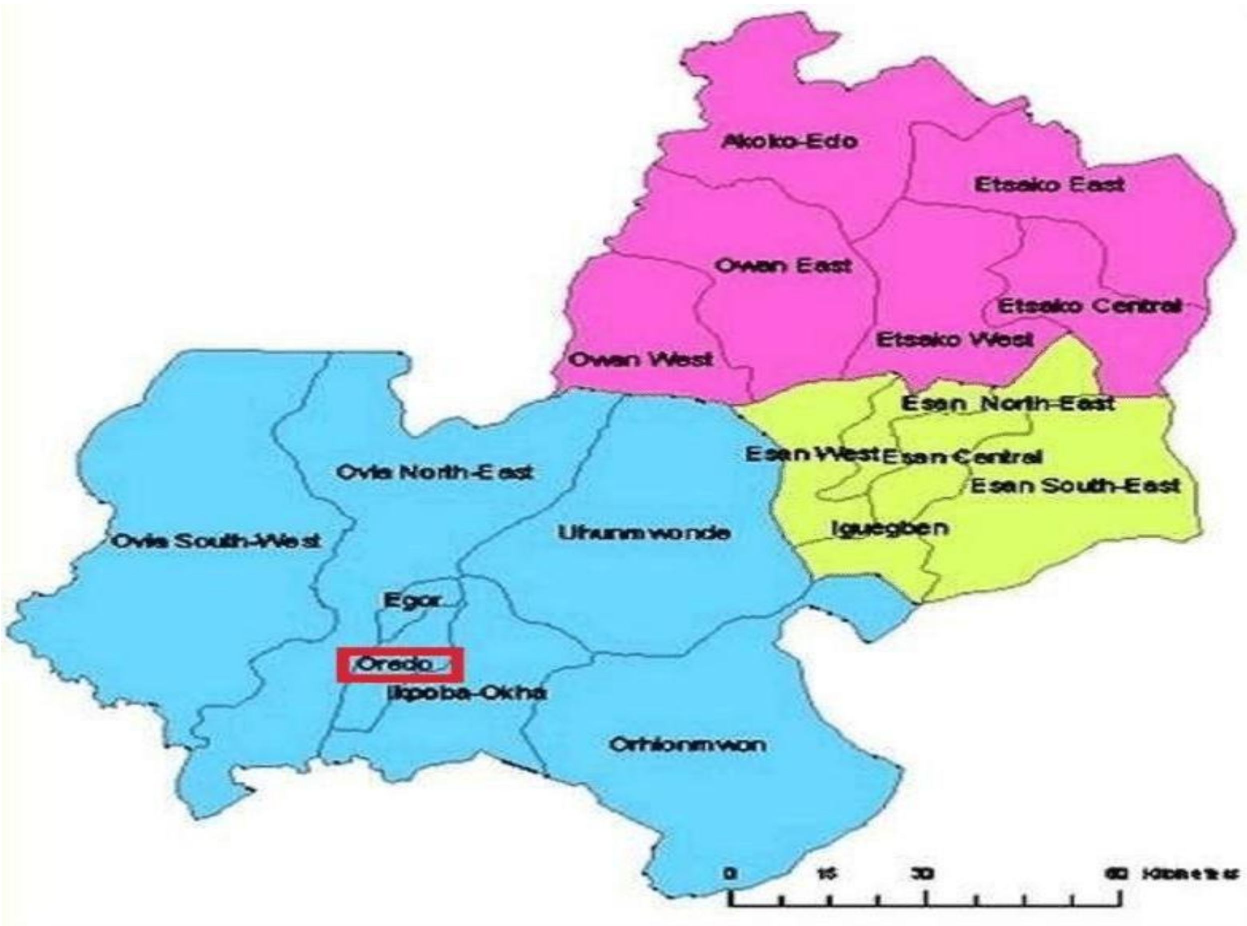

Figure1: Map of Edo State with Oredo Local Government Area indicated in red rectangle. [8]

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.

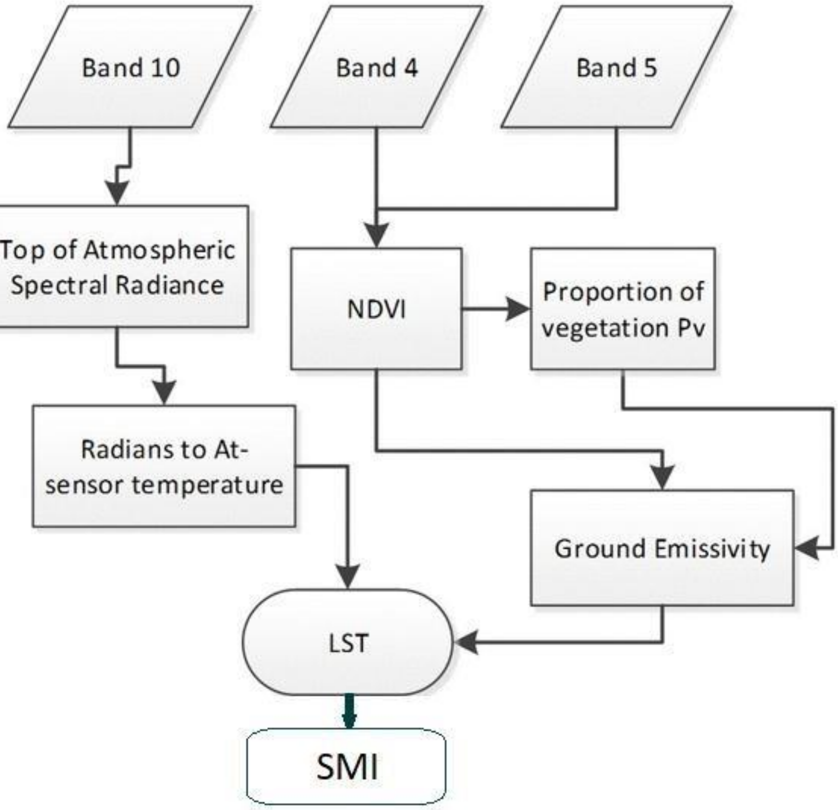

Fig. 2. Flowchart for SMI calculation (modified after Kaplan and Gordana, 2018)

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 [9]

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

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 [9]

$$\mathrm{BT} = \frac{\mathrm{K}_2}{\mathrm{In}\left[\left(\frac{\mathrm{K}_1}{\mathrm{L}_\lambda}\right)+1\right]} - 273.15 \qquad 2$$

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. [10]

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

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 [10]

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

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 [11]

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

2.8 Calculating Land Surface Temperature:

LST can be computed thus;

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

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).

2.9 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, 2021

YEAR(2021)	SENSOR ID	RESOLUTION(m)	SENSING TIME/DATE	CLOUD COVER	LOCATION
JAN-MAR.	OLI&TIRS	30	2021/03/29 T09:50:21.9845190Z	25	OREDO
APR-SEPT.	OLI&TIRS	30	2021/09/28 T09:57:05.9228569Z	30	OREDO
OCT-DEC.	OLI&TIRS	30	2021/12/17 T09:57:29.6797140Z	20	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 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 which we take to be possible flood prone area.

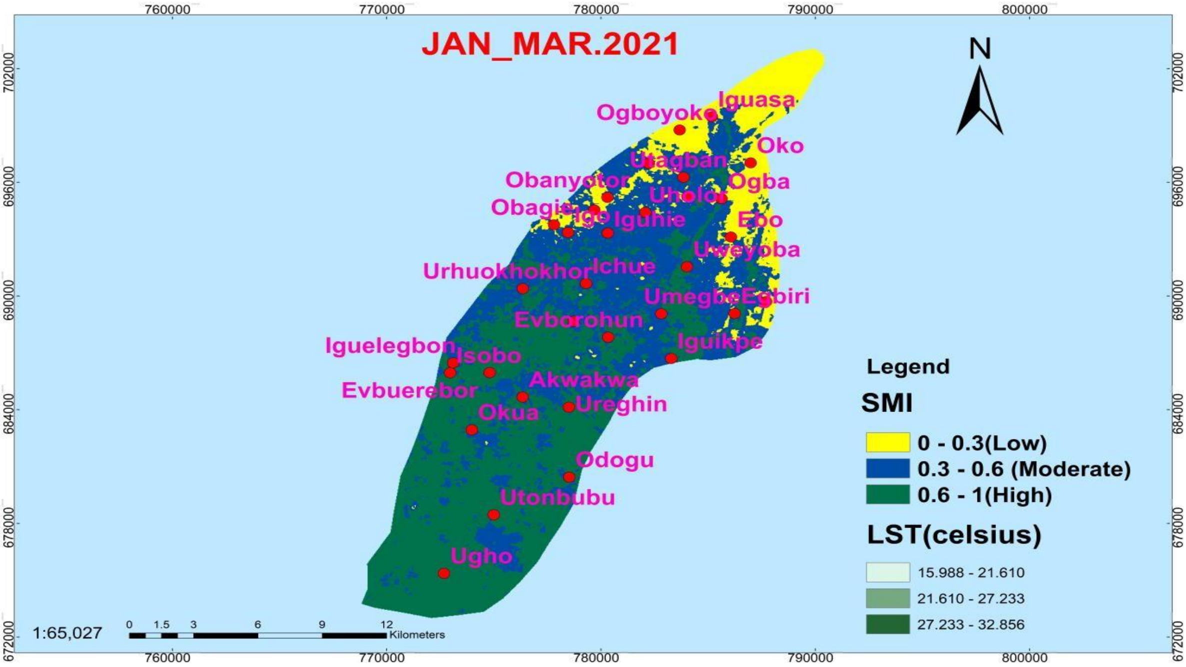

Figure 3: Soil moisture index map for 2021 dry season.

The moisture index for Jan. to Mar.2021, showed that a low moisture index class was observed in the northern region of the study area especially places like Iguasa, Ogboyoko, Oko, and Ebo. The moderate moisture index class occurs all over the study area as Uholor, and Igo fall within this class. The high moisture index occurs within the southern and eastern parts of the study area which may be classified as potential flooding area. These include areas such as Ugho, Odogu, Ureghin, Utonbubu, Okua fall in this class. The low moisture index covers 23.9%, and the moderate moisture index covers 37.5%, the high moisture index covers a little above 38.5%. The high moisture index class is the most dominant. The mean moisture index is 0.47, the standard deviation is 0.09.

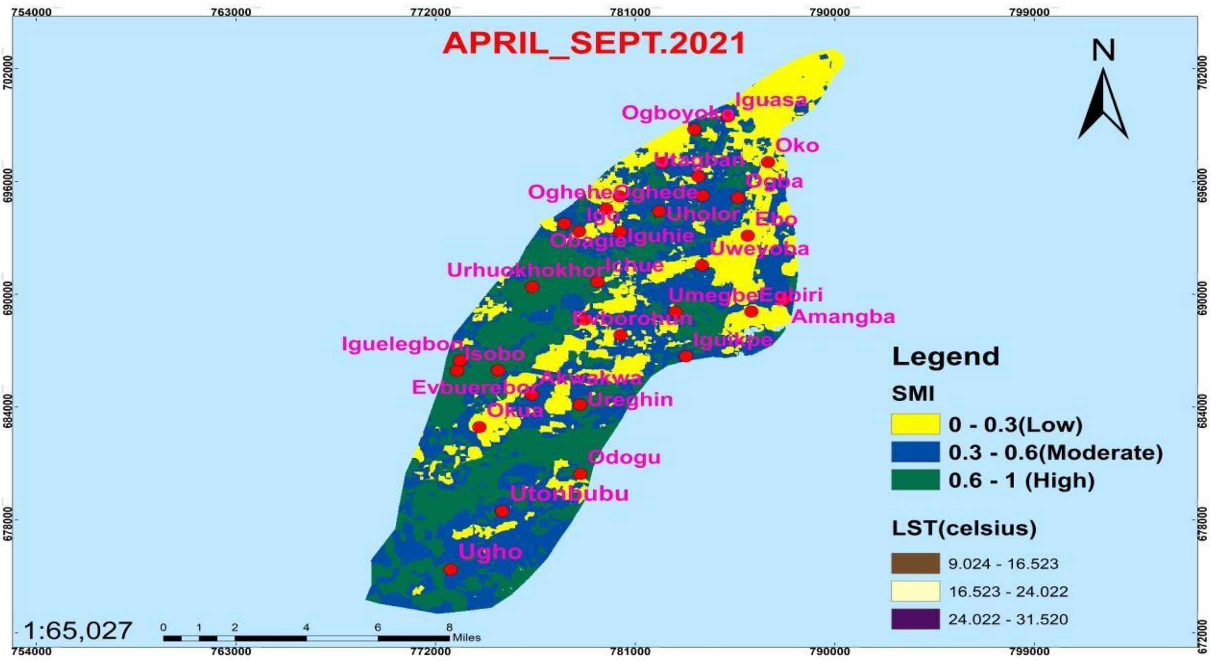

Figure 4: Soil moisture index map for 2021 wet season

The moisture index for April to September 2021, showed that a low moisture index class was in the northern region of the study area especially places like Iguasa, Oko, and Egbiri among others. The moderate moisture index class occurs all over the study area such as Akwakwa, Iguhie, and Oghede fall within this class. The high moisture index occurs within the southern and eastern parts of the study area. These include areas such as Ugho, Odogu, Ureghin, and Utonbubu. The low moisture index covers 15.9%, the moderate moisture index covers 31.5%, the high moisture index which may be possibly flood prone covers 52.5%, and 0.2% of the area was distorted by cloud cover. The mean moisture index is 0.44, the standard deviation is 0.15.

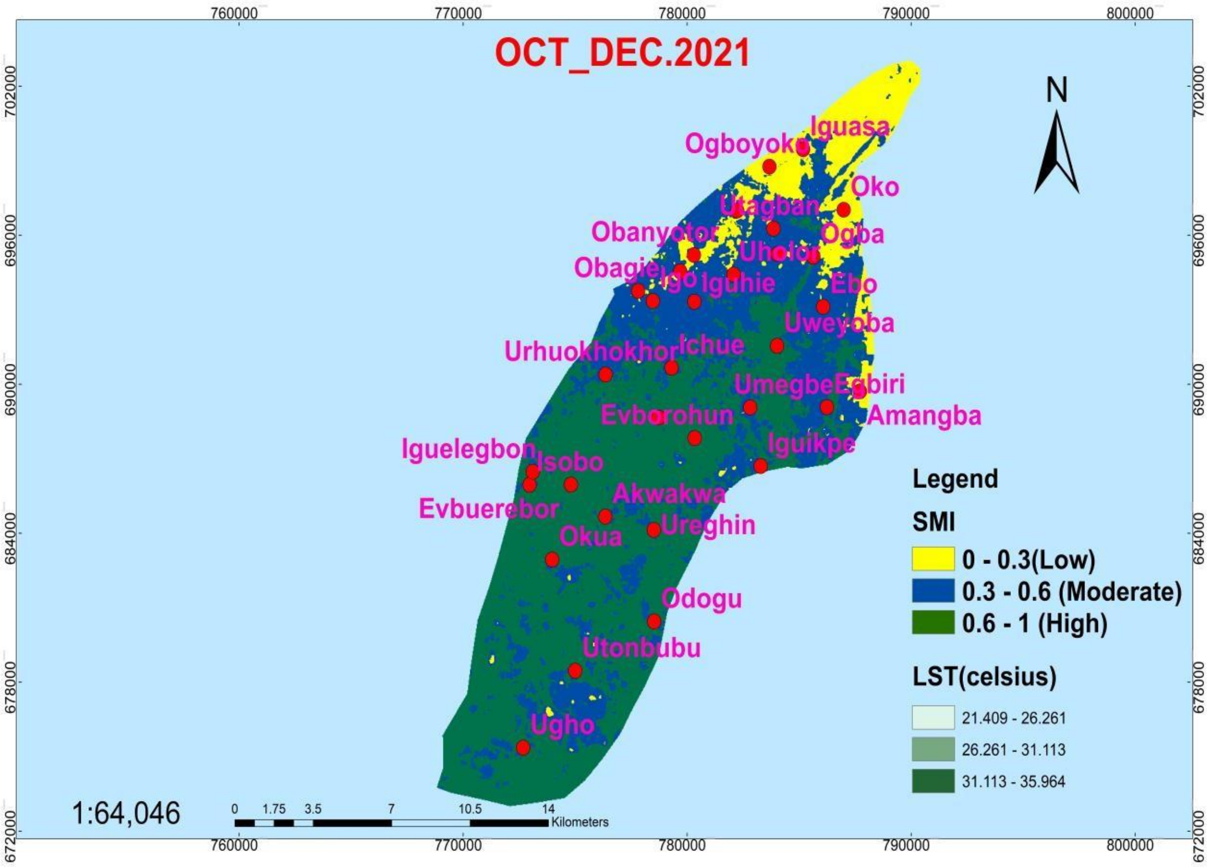

Figure 5: Soil moisture index map for 2021 dry season

The moisture index for October to December 2021, showed that a low moisture index class was observed in the northern region of the study area especially places like Iguasa, Ogboyoko, and Oko. The moderate moisture index class occurs all over the study area such as Obagie, Uweyoba, Ichue, and Igo fall within this class. The high moisture index occurs within the southern and eastern parts of the study area. These include places such as Ugho, Odogu, Ureghin, Utonbubu, and Okua fall in this class. The low moisture index covers 11.2%, the moderate moisture index covers 33.1%, and the high moisture index covers 55.7%. The high moisture index class is the most dominant. The mean moisture index is 0.64, the standard deviation is 0.11

Table 2. Percentage of soil moisture index 2021, distribution in Oredo LGA Benin City.

	DRY SEASON			WET SEASON		
YEAR	**HIGH(%)**	**MODERATE(%)**	**LOW(%)**	**HIGH(%)**	**MODERATE(%)**	**LOW(%)**
2021	**42.10**	**35.3**	**22.55**	**52.5**	**31.5**	**15.9**

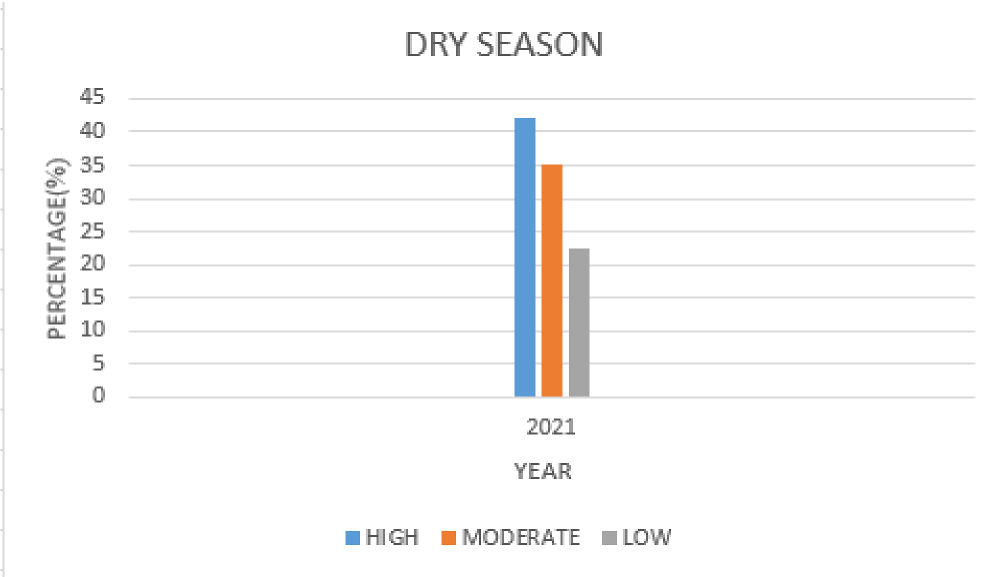

Figure 6: Bar Chart showing the percentage of soil moisture index.

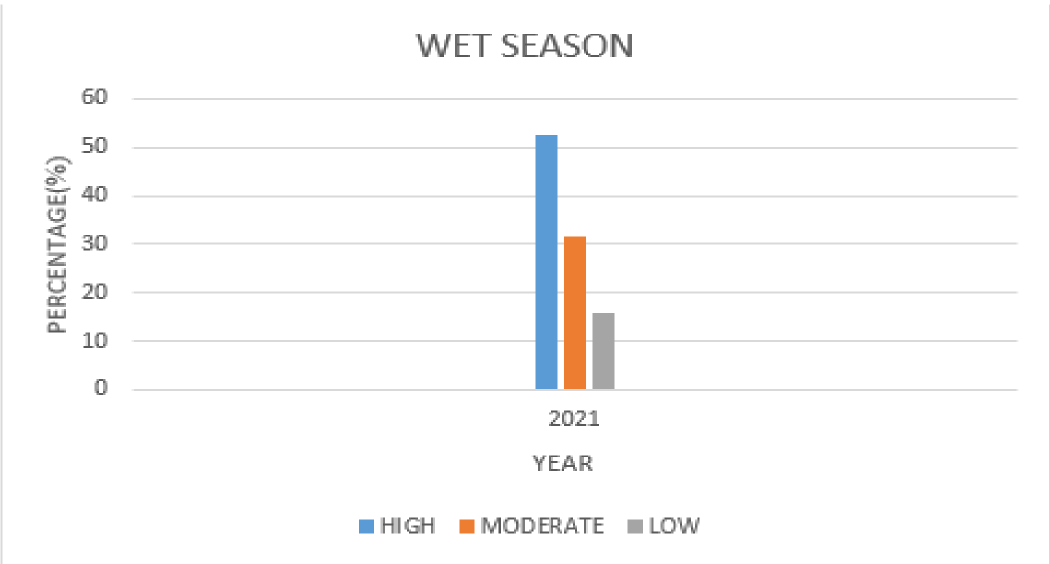

Figure 7: Bar Chart showing the percentage of soil moisture index.

4. Conclusion

In this research, a prediction of soil moisture model has been applied to Oredo Local Government Area of Edo State Nigeria, which demonstrates the power of remotely sensed data. The result shows that over fifty percent of the study area have high moisture index within while the remaining area have moderate to low moisture index during the wet season. The data also shows that during the dry season the area within the local government with high moisture index is a little above forty percent, while the remaining sixty percent have between moderate to low moisture index. This may indicate high to moderate water retention capacity of groundwater within the study area which may not be completely separated from recent media flood report around the local government. A proactive action in the form of detailed study using other geophysical and geotechnical methods is recommended with a view to arresting any perceived hazard to lives and properties. This study has shown the application of remote sensing in deciphering soil moisture index and its application in planning flooding management strategies. The soil moisture map obtained by this model was able to show good soil moisture variation within the studied area.

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