Nigerian Research Journal of Engineering and Environmental Sciences 9(2) 2024 pp. 813-824
p ISSN: 2635-3342; e ISSN: 2635-3350

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

RJEES

Original Research Article

GIS-Based Impact Assessment of Landscape Characteristics on Soil Moisture Distribution in Mambilla Plateau, Taraba State, Nigeria

***[1]Abdulkadir, T.S., [1]Abioye, M.E., [1]Olofintoye, O.O., [2]Tibenderana, P., [2]Bainomugisha, J., [3]Ako, T., [4]Agwe, T.M. and [1]Aderemi, I.A.**

[1]Department of Water Resources and Environmental Engineering, University of Ilorin, Ilorin, Nigeria.
[2]Department of Civil Engineering, Faculty of Engineering, Technology, Applied Design and Fine Art, Kabale University, P.O. Box 317, Kabale, Uganda.
[3]Department of Civil Engineering, University of Jos, Jos, Nigeria.
[4]Department of Civil Engineering, School of Engineering and Technology, Soroti University, Uganda.
*abdulkadir.ts@unilorin.edu.ng

http://doi.org/10.5281/zenodo.14566246

ARTICLE INFORMATION

Article history:
Received 04 Nov. 2024
Revised 01 Dec. 2024
Accepted 05 Dec. 2024
Available online 30 Dec. 2024

Keywords:
Landscape characteristics soil
Moisture index
Aspect
Soil texture
Surface temperature

ABSTRACT

Soil moisture is a crucial parameter linked to environmental issues like drought, erosion, flood and landslide. Its significance necessitates the need to understand the variables that could influence its distribution especially in a rugged watershed. Thus, this study assessed the impact of landscape characteristics such as slope, aspect, elevation and soil texture on the spatial distribution of soil moisture index in Mambilla Plateau, Nigeria. Landsat 8 data was applied to evaluate soil moisture, Digital Elevation Model for the landscape characteristics and digital soil map for soil texture in ArcMap environment. The results indicated that elevation, slope and normalized difference vegetation index (NDVI) ranged from1384 to 2399 m, 0 to 155.7% and -0.23 to 0.70. respectively. The soil moisture index (SMI) values ranged from 0.0 to 0.36 with average and standard deviation of 0.17 and 0.09 respectively. Analysis of developed SMI map indicated that the average SMI was higher in the western than eastern regions. Further analysis of impact of landscape characteristics on SMI on pixel-based correlation showed that higher values of average SMI occurred predominantly in areas having higher elevation, with gentler slopes, facing the western direction and having a relatively low proportion of sand. The sandy-clay-loam (26:8:66) texture which has the highest proportion of sand had the lowest average SMI value. This study would be beneficial to watershed managers and farmers in sustainable irrigation planning, geo-hazards and drought monitoring and prediction.

1. INTRODUCTION

Soil moisture is a vital variable which influences the hydrologic cycle. It affects volume of available water recharging ground water and surface water in a watershed. As a result, its assessment is very crucial for some environmental studies and applications such as irrigation and cultivation planning, drought assessment, flood prediction, etc. (Sholagberu *et al.*, 2018; Saha *et al.*, 2018). For instance, efficient irrigation planning for increasing plant yield and avoidance of excessive irrigation depend largely on soil moisture data (Tuller *et al.*, 2019). Studies have highlighted the significance of soil moisture as a key parameter for flood, erosion and landslide prediction, drought assessment and forecasting, numerical weather prediction, among others (Kavzoglu *et al.*, 2015; Brocca *et al.*, 2017; Scherer *et al.*, 2017; Ajaz *et al.*, 2018; Abdulkadir *et al.*, 2019).

A basic understanding of soil moisture and its spatiotemporal variability is indispensable for various environmental applications. Hence, techniques for assessing, monitoring and modelling soil moisture have been developed and applied. There are various in-situ techniques of determining the soil moisture of an area. Some of such methods are gravimetric, electrical-resistance, tensiometric, gamma-ray attenuation and radiological techniques. However, these methods have their limitations in large areas of land. Through advancement in technology, feasible alternatives have been developed. These alternative techniques are the applications of remote sensing and geographic information system (GIS). These present reliable substitutes for traditional methods which capable of covering massive areas and provide information about the spatial and temporal variability of soil moisture index (Klemas *et al.*, 2014; Mohamed *et al.*, 2020). Due to highly temporal and spatial dynamism of soil moisture, it is difficult and unrealistic to interpolate or extrapolate point information over a district or state level (Sharma *et al.*, 2018). In the determination of soil moisture and landscape characteristics in the field using traditional technique, an often and persistent issue has been the inability to measure and acquire data over a large area of land within a short period of time. This, coupled with the laborious nature of the task had posed difficulties in field measurement techniques. In addition, field measurements in mountainous regions are not feasible as the safety of the geologists and engineers involved is compromised.

Owing to significance of soil moisture, it is imperative to understand the variables that could influence the soil moisture in a watershed. Some of the reported variables are soil type, landscape characteristics and atmospheric parameters which control its spatial and temporal variability (Ahlmer *et al.*, 2018). However, ruggedness of landscape characteristics of mountainous areas needs to be evaluated. Thus, this study is aimed at assessing the impact of landscape characteristics on the distribution pattern of soil moisture index on the Mambilla Plateau, Taraba State, Nigeria.

2. MATERIALS AND METHODS

2.1. Description of Study Area

The Mambilla Plateau (Figure 1) is in the eastern part of Taraba State, Nigeria located on the coordinates 7.333°N 11.717°E and 7°20′N 11°43′E. The Plateau has an average elevation of about 1,600 m above sea level, making it the peak Plateau in Nigeria. It is the highest mountain in West Africa with areas like Gang or Chappal Waddi on about 2,419 m above sea level. The Mambilla Plateau is about 96 km along its curved length and 40 km wide. The Plateau covers an area of over 9,389 km^2. The Plateau is formed by tertiary to recent volcanic rocks with different lithological units (Omisore *et al.*, 2016). Basalt is reported to be predominant and is highly weathered on most parts. Studies by Omisore *et al.* (2016) suggest that the weathering could be due to the inherent chemicals in the area. The vegetation on the plateau comprises low grasses of velvet grass. It contains many plants which are endemic to the afromontane region which makes it a priority for conservation (Aderopo, 2013).

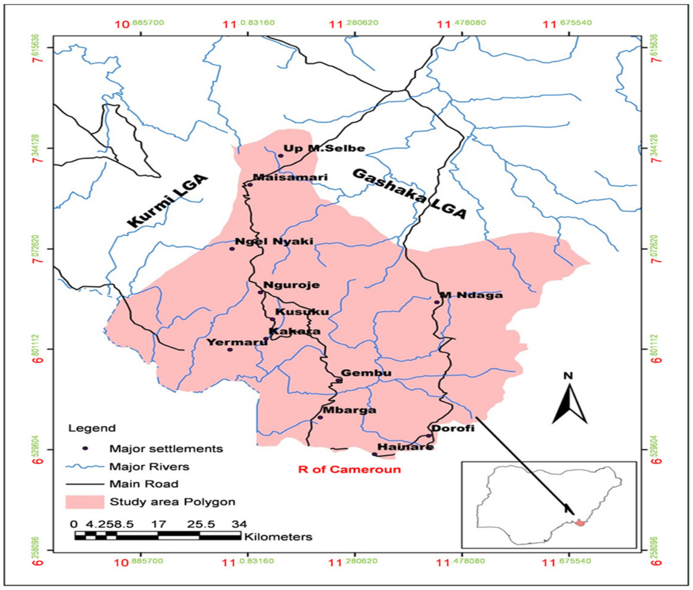

Figure 1: Location map of Mambilla Plateau (Source: Salako *et al.*, 2016)

2.2. Methods

This section entails the steps and actions that are necessary to achieve the aim of this study. It comprises of data collection, pre-processing of acquired data, data processing, data output and analysis. A representation of the methodological framework is presented in Figure 2.

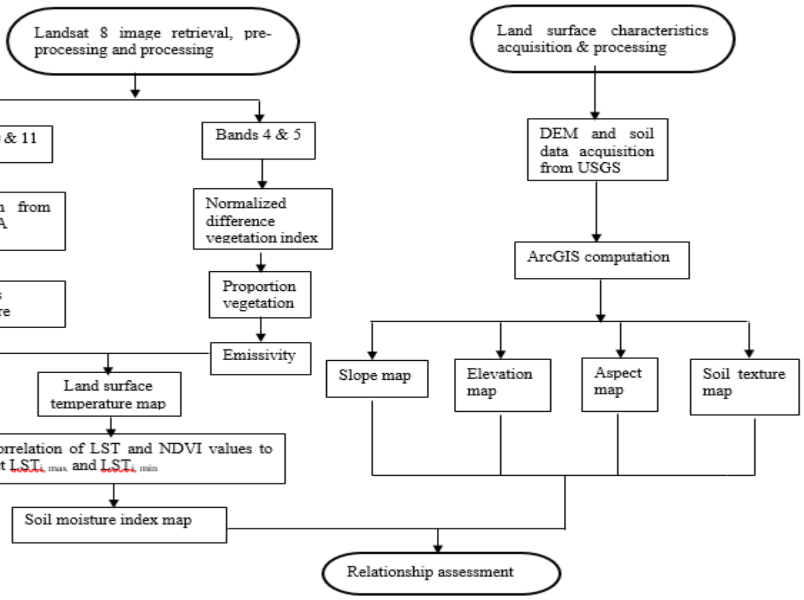

Figure 2: Methodological framework

2.2.1. Data collection

United States Geological Survey (USGS) archives Landsat 8 data from which it was retrieved for the study area. The Landsat image was taken on a suitable date with relatively low cloud cover. The location Row/path is recorded as 055/186 and Coordinates of the center of Image are Latitude 7^{o}13’ 52.61"N and Longitude 11^{o}07’ 45.98” E as provided by the Landsat metadata. This data was used for the evaluation of soil moisture index of Mambilla Plateau, Nigeria. Also, Digital Elevation Model (DEM) was also retrieved from USGS archive for the evaluation of land surface characteristics of Mambilla Plateau. The soil map of the study area was extracted from digital world soil map, which was acquired from the United Nations Food and Agriculture Organization (FAO) website. This data was used to develop the soil texture map of Mambilla Plateau for further analysis.

2.2.2. Processing of spatial data

Data acquired by Landsat sensors are subject to distortion owing to sensor, solar, atmospheric, and topographic effects. The preprocessing of remotely sensed data endeavors to abate these effects to the acceptable degree for specific applications (Young *et al.*, 2017). The preprocessing involves the application of Equation (1) for the conversion of digital numbers (DN) to "top of atmosphere" (TOA) reflectance which is termed radiometric calibration (Amazirh *et al.*, 2018). This was achieved using raster calculator in the spatial analyst tools of the ArcMap.

$$L_\lambda = M_L Q_c + A_L \tag{1}$$

Where: L_λ = TOA spectral radiance (m^2 s radμm^{-1}), M_L = radiance multiplicative band number, A_L = radiance additive band number; Q_C = quantized and calibrated digital number.

Also, the raw DEM for the study area was preprocessed by assigning Universal Transverse Mercator (UTM) projection. Then, the projected DEM was hydrologically corrected by filling the sinks with the use of the filling tool, to establish the flow direction and flow accumulation using "ArcHydro tool" extension of ArcMap.

2.3. Data processing

Soil moisture index and land surface characteristics of Mambilla Plateau were evaluated in ArcMap environment after being preprocessed. The land surface characteristics considered in this study were slope, elevation, aspect and soil texture. The required procedures are presented as follows:

2.3.1. Soil moisture index evaluation

The following are the steps entailed in processing data to acquire the soil moisture index pixel-based as described by Sholagberu *et al.* (2018):

a). *Brightness temperature, B_T derivation*: This is a measure of the radiance of microwave radiation travelling upward from the top of the earth's atmosphere. It was derived using Equation (2) with the specific thermal conversion constants for the Landsat Bands 10 and 11 obtained to be (K_1= 799.0284 and K_2=1329.2405) and (K_1= 475.6581 and K_2=1198.3494) respectively (Choung *et al.*, 2018). B_T was obtained using Plank's law as presented in Equation 2. The average B_T value was then used as the representative B_T for further calculations.

$$B_T = \frac{K_2}{ln\left\{{K_1}/{L_\lambda}+1\right\}} \tag{2}$$

b). *Normalized difference vegetation index* (NDVI): This was calculated in ArcGIS using Equation (3). Bands 4 and 5 of Landsat 8 represent the red and near infrared regions respectively.

$$NDVI=\frac{Band5-Band4}{Band5+Band4} \tag{3}$$

c). *Proportion vegetation, Pv*: This was calculated in ArcGIS environment using Equation (4).

$$P_v = \left\{\frac{NDVI-NDVI_{min}}{NDVI_{max}-NDVI_{min}}\right\}^2 \tag{4}$$

The maximum, $NDVI_{max}$ and minimum, $NDVI_{min}$ were values of NDVI obtained from Bands 4 and 5 of the Landsat 8 data.

d). *Emissivity, e*: The land surface emissivity is estimated using Equation (5) described as follows:

$$e = 0.004P_v + 0.986 \tag{5}$$

e) *Land surface temperature,* LST: This was calculated with the formula in Equation (6):

$$LST = {B_T}/_{\{1 + w\,B_T \ln(e)\,/P_v\}} \tag{6}$$

Where: B_T = brightness temperature, w = wavelength emitted radiance, e = emissivity.

f). *Soil moisture index:* Pixel-based soil moisture index was determined from Equation (7) using raster calculator:

$$SMI = {\{LST_{i,max} - LST_i\}}/_{\{LST_{i,max} - LST_{i,min}\}} \tag{7}$$

$LST_{i,max}$ = maximum LST and $LST_{i,min}$ = minimum LST values for a given NDVI. LST_i = observed instantaneous surface temperature.

The first step in evaluating the impacts of landscape characteristics on spatial distribution of soil moisture index, is to use the “create fishnet” function under data management tools in ArcMap to create a series of empty holes along the span of the study area. The next step is to fill these holes with data. This was achieved by using the “extract multi values to points” function under the extraction tools in the ArcMap toolbox. This process was done for elevation, slope, soil texture, aspect and soil moisture index maps. Then, the data points were processed in Microsoft Excel for further analyses.

3. RESULTS AND DISCUSSION

3.1. Soil Moisture Index Analysis

In the course of development and evaluation soil moisture index map, NDVI which is used to quantify vegetation greenness of an area was developed. The NDVI values obtained range between -0.23 and 0.73 as shown in Figure 3. More so, LST which is the radiative skin temperature of earth surface as measured in the direction of the remote sensor was also estimated. It is the temperature of combination of vegetation and bare soil. The LST map of the study area is shown in Figure 4. The aspect of study area controls variables like temperature, moisture, water availability and retention, rate of vegetation depletion and soil development (Zhi *et al.*, 2020). These abilities of aspect also determine the LST as sun facing slopes are hotter than the leeward sides (Zhi *et al.*, 2020; Tukura *et al.*, 2022).

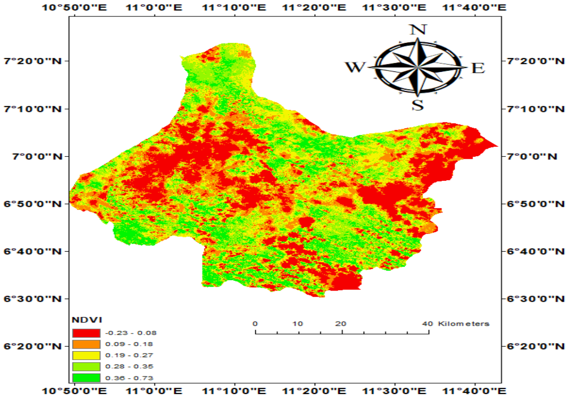

Figure 3: NDVI map

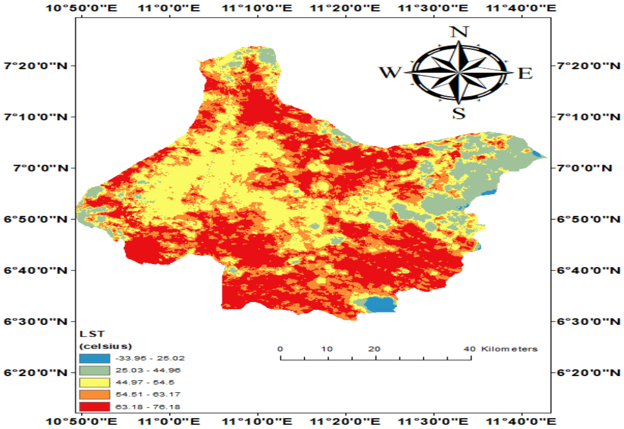

Figure 4: LST map

The SMI is the fraction of the variance between the current soil moisture and the permanent wilting point to the field capacity and the residual soil moisture. The index values are between 0 and 1 representing extreme dry and extreme wet conditions. The SMI map of Mambilla Plateau is presented in Figure 5. The SMI obtained for the study area ranges between 0 and 0.36. This indicates that the study area is fairly dry as the highest index value within the area is less than 0.5.

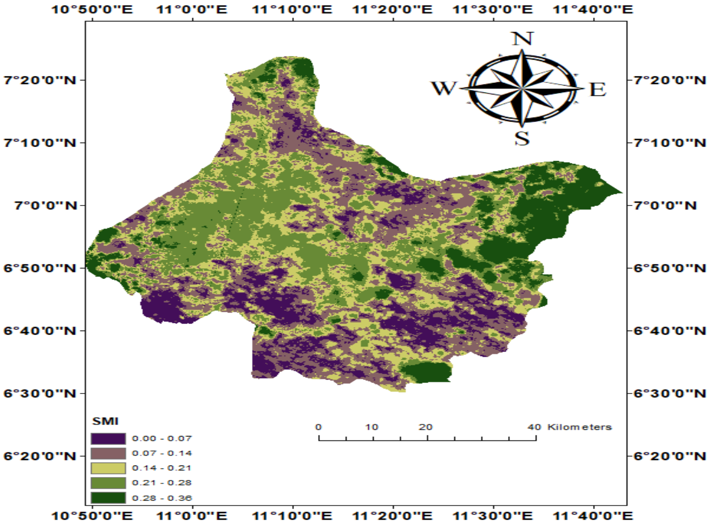

Figure 5: Soil moisture index map

3.2. Land Surface Characteristics Maps

The land surface characteristics considered in this study includes soil texture, elevation, slope and aspect. These are presented in maps for the area under consideration as shown in Figures 6, 7, 8 and 9 respectively. The soil texture was classified into eight categories in terms of the ratios of its clay, silt and sand contents. Elevation map developed for the study area was classified into 5 categories ranging 259 to 2399 m. The results showed that the study area is mountainous with larger areas having elevation values ranging between 1384 and 2399 m. The area was classified into five manageable units for efficient spatial modeling (Abwage and Sale, 2023). This result is similar to that obtained by Salako *et al.* (2016). The slope of an area is the change in vertical distance with respect to horizontal distance covered when travelling in a given direction. It can be expressed in degrees or as a percentage. From

Figure 8, slope of Mambilla Plateau ranges between 0 and 155.7%. This revealed the steepness of the study area which often subject it to high runoff resulting into soil erosion (Tukura *et al.*, 2022).

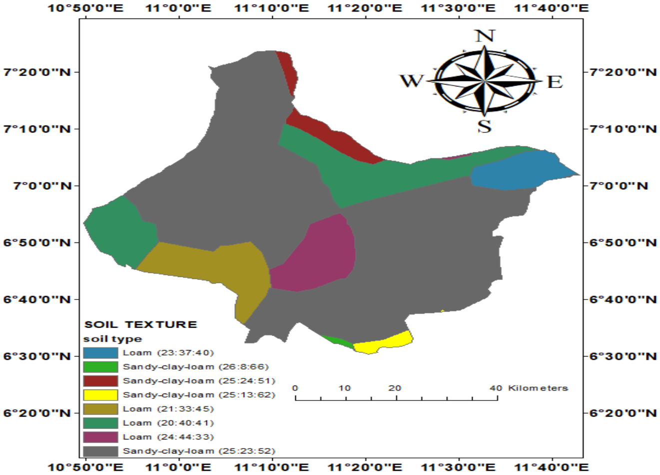

Figure 6: Soil texture map

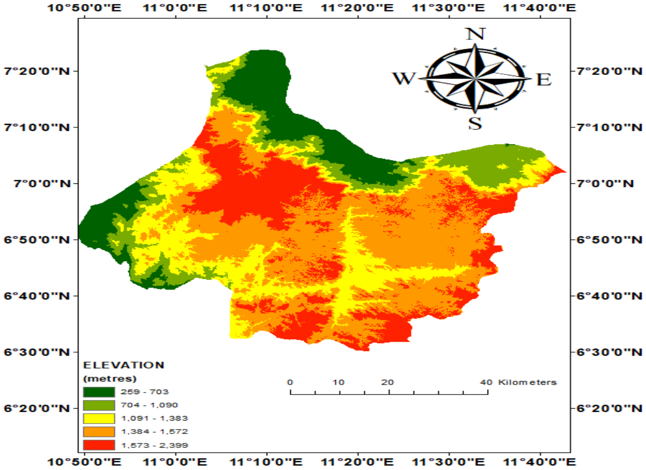

Figure 7: Elevation map

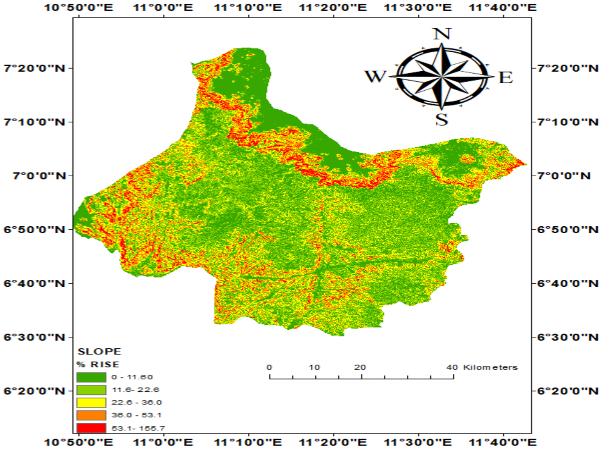

Figure 8: Slope map

The Aspect is referred to as the direction that a topographical slope faces, typically measured in degrees from North. It is usually classified into 8 categories as presented in Figure 9. According to Tukura *et al.* (2022), slope of a watershed determines the thickness of soils, amount of sun's rays, the quantity of surface runoff and vegetation density.

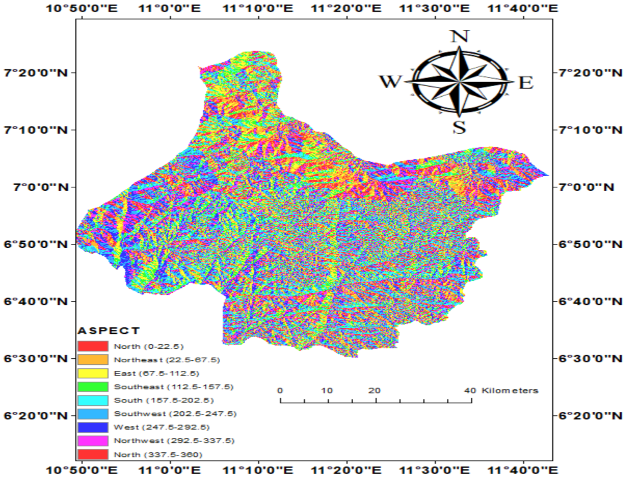

Figure 9: Aspect map of the study area

3.3. Land Surface Characteristics and SMI

Impacts of land surface characteristics such as elevation, slope, aspect and soil texture on soil moisture index of Mambilla Plateau were evaluated. The results of these analyses could be useful in irrigation planning and scheduling, flood and erosion modeling and prediction among others.

3.3.1. Impact assessment of elevation and slope on soil moisture index

From Figure 10, it can be deduced that at higher elevations (1573-2399 m), average soil moisture index was the highest. This indicates that elevation has positive relationship with soil moisture index. The result is an agreement with the study conducted by Sholagberu *et al.* (2018). This is because at higher elevations, there is fewer human activities. Hence, there is more vegetation in this area. This, in turn results in higher soil moisture index due to the lower emissivity of vegetated areas (Sholagberu *et al.*, 2018).

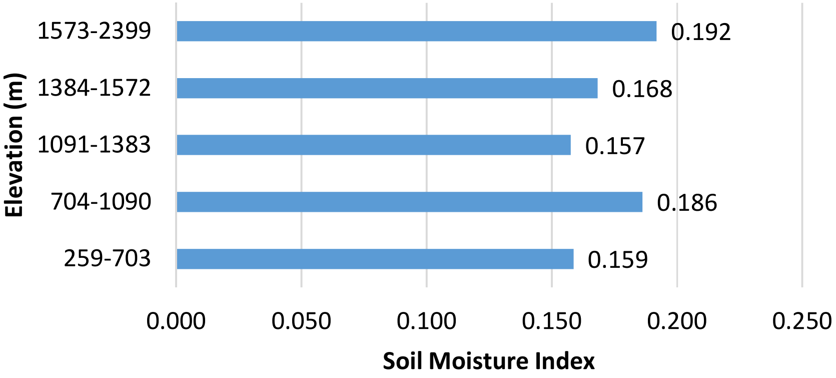

Figure 10: Elevation against soil moisture index

Figure 11 shows that locations with higher sloping percentage, has lower soil moisture index. This highlights that slope has a negative relationship with the SMI of that area. This is due to the fact that at higher slopes, surface runoff moves faster under the influence of gravity. This results in less time for runoff water to infiltrate the soil which consequently lower the SMI values. Thus, as the slope of the terrain increases, the volume of water infiltrating into the soil profile declines (Jakšić *et al.*, 2021). Conclusively, the spatial variation in soil moisture content was strongly affected by terrain gradient and elevation as confirmed by Guo *et al.* (2020).

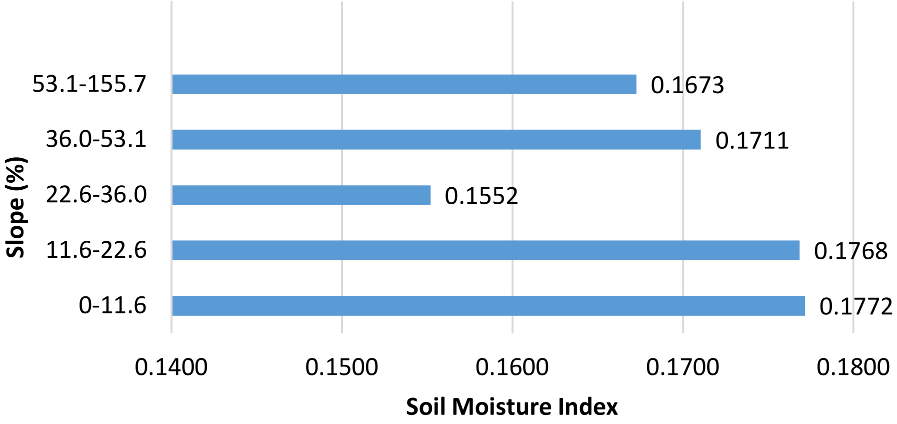

Figure 11: Slope against soil moisture index

3.3.2. Impact assessment of aspect and soil texture on SMI

In evaluating the impacts of aspect on the spatial variation and distribution of soil moisture, aspect map was classified into eight categories such as North, North-East, East, South-East, South, South-West, West, and North-West. The aspect classification of the study area was evaluated against soil moisture as presented in Figure 12.

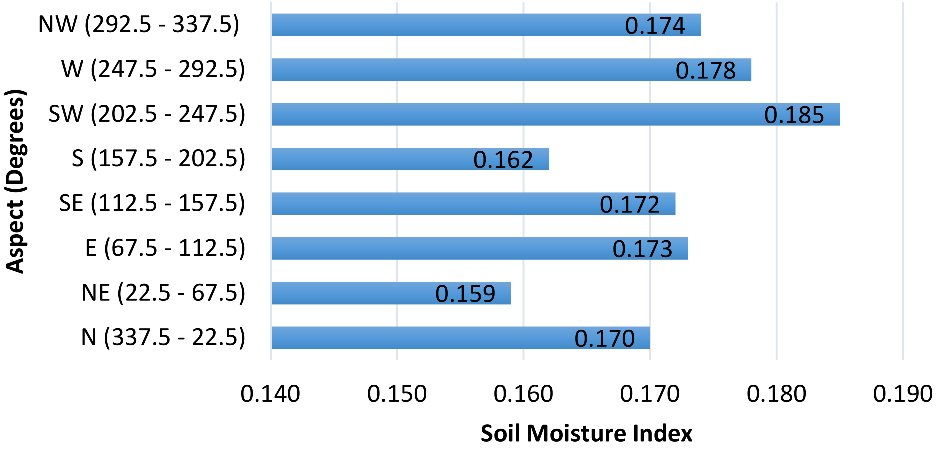

Figure 12: Aspect against soil moisture index

It was observed that the average SMI in the western regions is higher than that in the eastern regions. This means that the east facing slope receives more solar radiation resulting in increased evapotranspiration, which further results in lower SMI values compared to the western region. Also, the average SMI in the North (0.170) was much higher than that in the South (0.162).This is due to the fact that in the Northern Hemisphere (which Nigeria is a part of), slopes facing north receive low direct sunlight than the slopes facing south (Jakšić *et al.*, 2021), thereby experiencing less evapotranspiration.

Moreover, the highest average SMI was found in the south-west (0.185), while the lowest was in the north-east (0.159). This highlights how much impact aspect has on soil moisture of Mambilla Plateau.

Similarly, soil texture map was categorized by the fraction of sand, silt and clay contained. The soil texture in the study area was categorized into eight having different proportions sandy-clay-loam. Soils that are in the ratio 20:40:40 of clay to silt to sand are referred to as loam soils while those in which the clay content and sand content are each greater than the silt content are referred to as sandy-clay-loam. As such, the soil texture map was classified into eight categories. Then, average SMI within each class were evaluated and plotted as shown in Figure 13.

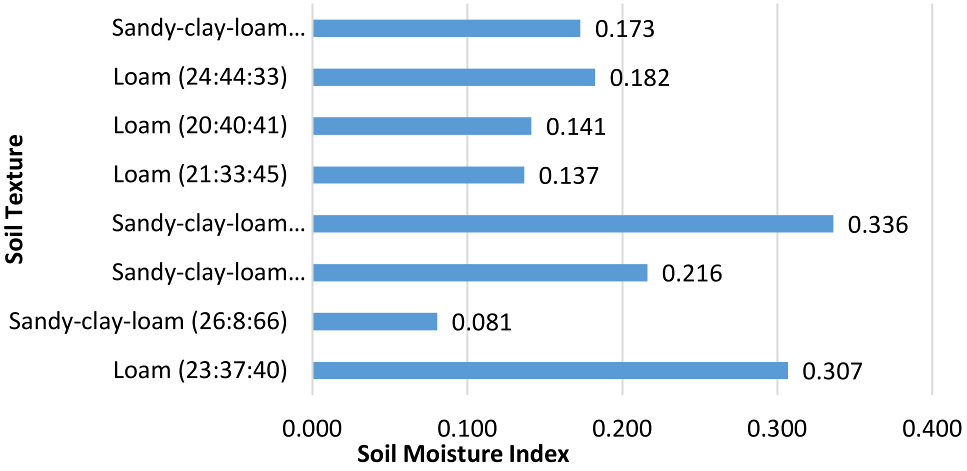

Figure 13: Soil texture against soil moisture index

From Figure 13, sandy-clay-loam (26:8:66) which has the highest quantity of sand by proportion has the lowest average SMI value. This is due to the high porosity of sand which results in the rapid drainage of the soil down the strata. Therefore, there is a negative correlation between sand proportion and SMI. The same trend can be seen across Loam (24:44:33), Loam (20:40:41) and Loam (21:33:45), as the sand proportion increases, the average SMI reduces. Even when comparing Loam (23:37:40), Sandy-clay-loam (25:24:51), Sandy-clay-loam (26:8:66) as the sand proportion increases the SMI decreases accordingly. However, the soil texture which has the highest average SMI is Sandy-clay-loam (25:13:62).

4. CONCLUSION

Soil moisture is an important parameter which is used in various water resources related studies such as irrigation, drought analysis, reservoir management, flood control, etc. As a result, there is need for the evaluation of its spatiotemporal variability in a watershed. The distribution of soil moisture is affected by a number of landscape characteristics. Hence, this study explored GIS and remote sensing techniques to evaluate the impact of landscape characteristics on spatial distribution of soil moisture in a mountainous Mambilla Plateau, Nigeria. For this study, impact of landscape characteristics namely: elevation, aspect, slope and soil texture on soil moisture index were evaluated. Elevation had a positive correlation with SMI. This means that at higher elevations there tends to be higher values of soil moisture index. A key reason for this is the fact that at higher elevations there tends to be more vegetation cover due to reduced human activities, resulting in higher levels of moisture preservation. Slope showed a negative relationship with SMI, i.e., areas with higher sloping percentages have lower SMI values. This is due to the fact that when water runs on surfaces with higher slopes it moves quicker under the influence of gravity when compared to those with gentler slopes. This causes the SMI values to be lower since the running water has less time to infiltrate the soil. The average soil moisture in the regions facing towards the west is higher than those facing the east. This means that the east facing slope receives more solar radiation which causes it to have increased evapotranspiration, which further results in lower SMI values than those facing west. Furthermore, the proportion of sand in the area showed negative correlation with SMI. This is due to the high porosity level of sand as compared to silt and clay which have good water retaining capacities. This study would be beneficial to the watershed managers and other stakeholders such as farmer in sustainable irrigation management, modeling and prediction of soil moisture related geo-hazards.

5. ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of United States Geological Survey (USGS) and United Nations Food and Agriculture Organization (FAO) for provision of spatial data toward the successful completion of this work.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Abdulkadir, T.S., Muhammad, R.M., Khamaruzaman, W.Y., Hashim, A.M. Mumtaz, M.S., Muhammad W.A. and Mohamed, H. (2019). Multivariate logistic regression model for soil erosion susceptibility assessment under static and dynamic causative factors. *Polish Journal of Environmental Studies,* 28 (5), pp. 3419-3429.

Abwage, W. D., and Sale, F. A. (2023). Assessment of land uses and land cover change of Ngel Nyaki Forest Reserve, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 15(4), pp. 75-85.

Aderopo, A. (2013). Vegetation Analysis of Ngel Nyaki Forest Reserve, Mambilla Plateau, Nigeria. *Journal of Natural Sciences Research*, pp. 3 (12), 121-125.

Ahlmer, A. K., Cavalli, M., Hansson, K., Koutsouris, A. J., Crema, S., and Kalantari, Z. (2018). Soil moisture remote-sensing applications for identification of flood-prone areas along transport infrastructure. *Environmental Earth Sciences*, 77 (14), pp. 1–17.

Ajaz, A., Taghvaeian, S., Khand, K., and Sutherland, A. (2018). Tracking Drought Using Soil Moisture Information. Oklahoma State University, October, 1–4.

Amazirh, A., Merlin, O., Er-Raki, S., Gao, Q., Rivalland, V., Malbeteau, Y., ... and Escorihuela, M. J. (2018). Retrieving surface soil moisture at high spatio-temporal resolution from a synergy between Sentinel-1 radar and Landsat thermal data: A study case over bare soil. *Remote Sensing of Environment*, 211, pp. 321-337.

Bellizzi, V., DeNicola, L., Minutolo, R., Russo, D., Cianciaruso, B., Andreucci, M., ... and Andreucci, V. (1999). Effects of water hardness on urinary risk factors for kidney stones in patients with idiopathic nephrolithiasis. *Nephron*, 81 (Suppl. 1), pp. 66-70.

Brocca, L., Ciabatta, L., Massari, C., Camici, S., and Tarpanelli, A. (2017). Soil moisture for hydrological applications: Open questions and new opportunities. *Water*, 9 (2), pp. 140.

Choung, Y.J., Chung, Y.I., and Choi, S.Y. (2018). Assessment of the relationship between air temperature and TOA brightness temperature in different seasons using Landsat-8 TIRS. *Journal of the Korean Association of Geographic Information Studies*, 21 (2), pp. 68-79.

Guo, X., Fu, Q., Hang, Y., Lu, H., Gao, F., and Si, J. (2020). Spatial variability of soil moisture in relation to land use types and topographic features on hillslopes in the black soil (Mollisols) area of northeast China. *Sustainability*, 12 (9), pp. 3552.

Jakšić, S., Ninkov, J., Milić, S., Vasin, J., Živanov, M., Jakšić, D., and Komlen, V. (2021). Influence of slope gradient and aspect on soil organic carbon content in the region of Niš, Serbia. *Sustainability* (*Switzerland*), 13 (15). pp. 8332 https://doi.org/10.3390/su13158332

Kavzoglu T., Sahin E.K., and Colkesen I. (2015). Selecting optimal conditioning factors in shallow translational landslide susceptibility mapping using genetic algorithm. *Engineering Geology*, 192, pp. 101-112.

Klemas, V., Finkl, C. W., and Kabbara, N. (2014). Remote sensing of soil moisture: An overview in relation to coastal soils. *Journal of Coastal Research*, 30 (4), pp. 685–696.

Mohamed, E. S., Ali, A., El-Shirbeny, M., Abutaleb, K., and Shaddad, S. M. (2020). Mapping soil moisture and their correlation with crop pattern using remotely sensed data in arid region. *The Egyptian Journal of Remote Sensing and Space Science*, 23 (3), pp. 347–353.

Omisore, B.O., Olorunfemi, M.O., and Sheng, J. (2016). Geoelectric investigation of a proposed Mambilla Plateau Airport Runway, Taraba State, Nigeria, 7th International Conference on Environmental and Engineering Geophysics & Summit Forum of Chinese Academy of Engineering, *Engineering Science and Technology*, pp. 243-246.

Saha, A., Patil, M., Goyal, V.C., and Rathore, D.S. (2018). Assessment and impact of soil moisture index in agricultural drought estimation using remote sensing and GIS techniques. *Proceedings*, 7 (1), pp. 2. https://doi.org/10.3390/ecws-3-05802

Salako, G., Olalubi, O., Sawyerr, H., Howe, G., Adebayo, A., and Adio, A. (2016). Using Multi Techniques Analysis in Biogeoclimatic Ecosystem Classification and Mapping of Mambilla Plateau in Taraba State Nigeria. *Open Journal of Ecology*, 6 (7), pp. 412-426.

Scherer, T. F., Franzen, D. and Cihacek, L. (2017). Soil, water and plant characteristics important to irrigation. *K-State Research and Extension*, 1675(December), pp. 1–8. www.ksre.ksu.edu/irrigate

Sharma, P. K., Kumar, D., Srivastava, H. S., and Patel, P. (2018). Assessment of different methods for soil moisture estimation: A Review. *Journal of Remote Sensing & GIS*, 9 (1), pp. 57–73.

Sholagberu, A. T., Ul Mustafa, M. R., Yusof, K. W., and Hashim, A. M. (2018). Geospatial assessment of soil moisture distribution in Cameron highlands using GIS and remote sensing techniques. Malaysian Construction Research Journal, 5 (3 Special issue), pp. 14–27.

Tukura, E. D., Oruonye, E. D., and Zemba, A. A. (2022). Terrain analysis for environmental sustainability in Taraba Central Senatorial Districts, North-East, Nigeria. *Forestry Research and Engineering: International Journal*, 5(1), pp. 34-42.

Tuller, M., Babaeian, E., Jones, S., Montzka, C., Vereecken, H., and Sadeghi, M. (2019). The paramount societal impact of soil moisture. In *EOS,* 100 (100). https://doi.org/10.1029/2019eo128569

Zhi, Y., Shan, L., Ke, L., and Yang, R. (2020). Analysis of land surface temperature driving factors and spatial heterogeneity research based on geographically weighted regression model. *Complexity*, 2020(1), 2862917.

Young, N. E., Anderson, R. S., Chignell, S. M., Vorster, A. G., Lawrence, R., and Evangelista, P. H. (2017). A survival guide to Landsat preprocessing. *Ecology*, 98 (4), pp. 920-932.