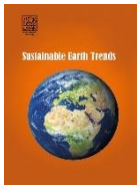
Shahid Beheshti University

Sustainable Earth Trends

Journal homepage: http://sustainearth.sbu.ac.ir



Assessment of soil moisture variability and its relationship with climate under different land uses in a tropical region

Brown Mang Onwuka[a*], Okechi Onwuka[a]

[a] Department of Water Resources Management and Agrometeorology, Michael Okpara, University of Agriculture, Umudike, Abia State, Nigeria

ABSTRACT

This study was carried out to assess soil moisture variability in relation to climate across different land uses in a tropical region, to evaluate the variations in climate and soil moisture under grassland, forest land, and continuously cultivated land. Soil moisture was measured weekly at two depths (0–20 and 20–40 cm) for the period of January 2024 to December 2024. Meteorological data (rainfall, temperature, sunshine duration, and soil moisture) in this study were obtained by remote sensing from the National Oceanic and Atmospheric Administration (NOAA). Line graph analysis was used to explain the variations of soil moisture and climate under different land use, while regression analysis showed the relationship between soil moisture and climate. The study showed that land use influenced atmospheric temperature, rainfall, and sunshine duration, with continuously cultivated land recording the highest temperature (29.38 °C). Forest land received higher rainfall (458.95 mm month^{-1}) than grass land and continuously cultivated land. The study also showed that forest land maintained higher soil moisture (1.88 kg kg^{-1}) levels than other land uses. Land use systems significantly influenced sunshine duration, with continuously cultivated land recording the highest sunshine duration (5.04 hours day^{-1}). The result also showed that soil moisture exhibited a negative relationship with sunlight duration and atmospheric temperature, and had a strong positive relationship with rainfall. The findings of this study can be used as important implications for sustainable land management practices, particularly in regions with limited water resources.

ARTICLE INFO

Keywords:
Climatic factors
Hydrology
Land management
Remote sensing
Soil moisture

Article history:
Received: 25 July 2025
Accepted: 22 September 2025

*Corresponding author
E-mail address:
onwuka.brown@mouau.edu.ng
(B.M. Onwuka)

Citation:
Onwuka, B.M. & Onwuka, O. (2026). Assessment of soil moisture variability and its relationship with climate under different land uses in a tropical region, *Sustainable Earth Trends:* 6(4), (1-14).

DOI: 10.48308/set.2025.240812.1146

1. Introduction

In recent decades, the dynamics of soil moisture have garnered increasing attention due to their essential role in regulating hydrological cycles, sustaining vegetation, and supporting agricultural productivity. Soil moisture serves as a bridge between the atmosphere and the land surface, making it very sensitive to climatic factors such as temperature, rainfall, solar radiation, and evaporation rates (Wu et al., 2023). The moisture in the soil is an important component of the Earth's terrestrial system, directly influencing plant growth, surface energy balance, hydrological processes, and agricultural productivity (Adigarla et al., 2025). In tropical regions, where seasonal rainfall governs ecological and agricultural cycles, soil moisture acts as both a sensitive indicator of climate variation and a key determinant of land use management. Kaur and Kaur (2017) stated that changes in temperature, precipitation patterns, and evaporation rates, affect how moisture is stored and distributed within the soil, impacting crop yields and groundwater recharge. The tropical region of Nigeria, consists of diverse landscape characterized by varying land use systems, including forest land, continuously cultivated farmland, and open grass land. Forests, agricultural fields, and grass lands each possess distinct vegetation cover, root structures, and land management practices, which alter soil structure and water retention capabilities. Forests tend to enhance infiltration

Copyright: © 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY). license (https://creativecommons.org/licenses/by/4.0/).

and maintain higher soil moisture due to dense canopy cover and organic matter (Koelemeijer et al., 2024). Consequently, continuously cultivated land may show reduced water retention as a result of soil compaction, tillage, and limited vegetative shielding (Oguike and Onwuka, 2017; Araya et al., 2022). Each of these land use systems interact differently with climatic inputs, influencing how water is stored, transmitted, and lost within the soil. With shifting rainfall patterns, rising temperatures, and increased anthropogenic pressure on land, the natural balance of soil water storage is becoming increasingly unstable, leading to declining soil fertility (Shahen et al., 2026), increased surface runoff and reduced crop productivity (Singh and Kumar, 2023). In tropical regions, where agriculture is related with rainfall and temperature patterns, soil moisture serves as a fundamental component of land productivity and hydrological balance (Spadotto and Mingoti, 2023). However, rising climate variability observed in irregular rainfall distribution, shifting temperatures, and prolonged dry spells, poses significant challenges to the conservation of soil water. Simultaneously, widespread changes in land use driven by population growth, deforestation, and intensive cultivation have altered the natural capacity of various landscapes to retain and regulate soil moisture. In spite of the importance soil moisture renders in sustainable agriculture and ecosystem conservation, there remains a lack of localized assessments examining how different land use systems in tropical environments respond to climatic fluctuations. Forested areas, farmlands under continuous cultivation, and grass lands each interact distinctly with climatic variables, yet their comparative performance in increasing or reducing soil water is poorly understood. Therefore, this study aims to assess soil moisture variability and its relationship with climate across different land use systems in a tropical region.

2. Material and methods

2.1. Study area

The research was carried out in Arochukwu Area (Fig. 1) located within latitudes 5°15′ - 5°28′N and longitudes 7°44′ - 8°03′ E (Ideozu et al., 2019). Arochukwu area have a mean population of 423 inhabitants in a square kilometer. The total area of Arochukwu is 524 km^2 (City population, 2024).

2.2. Climate

Arochukwu lies within Nigeria's tropical rainforest zone, experiencing a warm and humid climate throughout the year. The area receives an average annual rainfall of approximately 3000 mm, while yearly temperatures typically range from 26°C to 29°C (Nigeria Meteorological Agency, 2015). Relative humidity fluctuates between 75% and 90%. The region's climate is distinctly seasonal, comprising a wet period from April to October and a dry spell between November and March. Rainfall follows a bimodal distribution, peaking in July and September, with a short three-week dry spell in August referred to as the "August break" (Nigeria Meteorological Agency, 2015).

2.3. Vegetation and geology

Arochukwu is situated within Nigeria's rainforest zone, though much of the original vegetation has been replaced by secondary growth dominated by cocoa and rubber plantations, along with oil palm trees of varying density. This zone also features a mix of tall grasses, herbaceous plants, and woody shrubs like Chromolaena odorata (commonly known as Siam weed). Geologically, the area falls within the Deltaic marine sedimentary region, spanning from the Cretaceous period to the recent age (John et al., 2015). The geology of southeastern Arochukwu includes three major formations: the Nkporo Formation, composed primarily of shales and sandstones; the Mamu Formation, which contains shale, sandstone, and coal layers; and the Ajalli Formation, known for its false-bedded sandstones (Ideozu et al., 2019). The Ajalli Formation, originating from the Cretaceous age, is characterized by reddish, loosely packed sands forming thick and poorly sorted sandstone beds, which are capped by the Nsukka Formation.

2.4. Description of land uses

From the location of study, three land uses {continuously cultivated land (CC), grass land (GL) and forest land (FL)} were selected for the

study (Fig. 1). Continuously cultivated land has been used over the years to cultivate crops like fluted pumpkin, *Amaranthus spp*, maize, waterleaf, scent leaf using organic farming system. Grass land has been used for growing *Panicum maximum, Pennisetum purpureum* over the years. The forest has been in existence for more than six decades, hosting tree species like *Milicia excelsa* (iroko), *Swietenia mahagoni* (mahogany), and *Gmelina arborea* (gmelina).

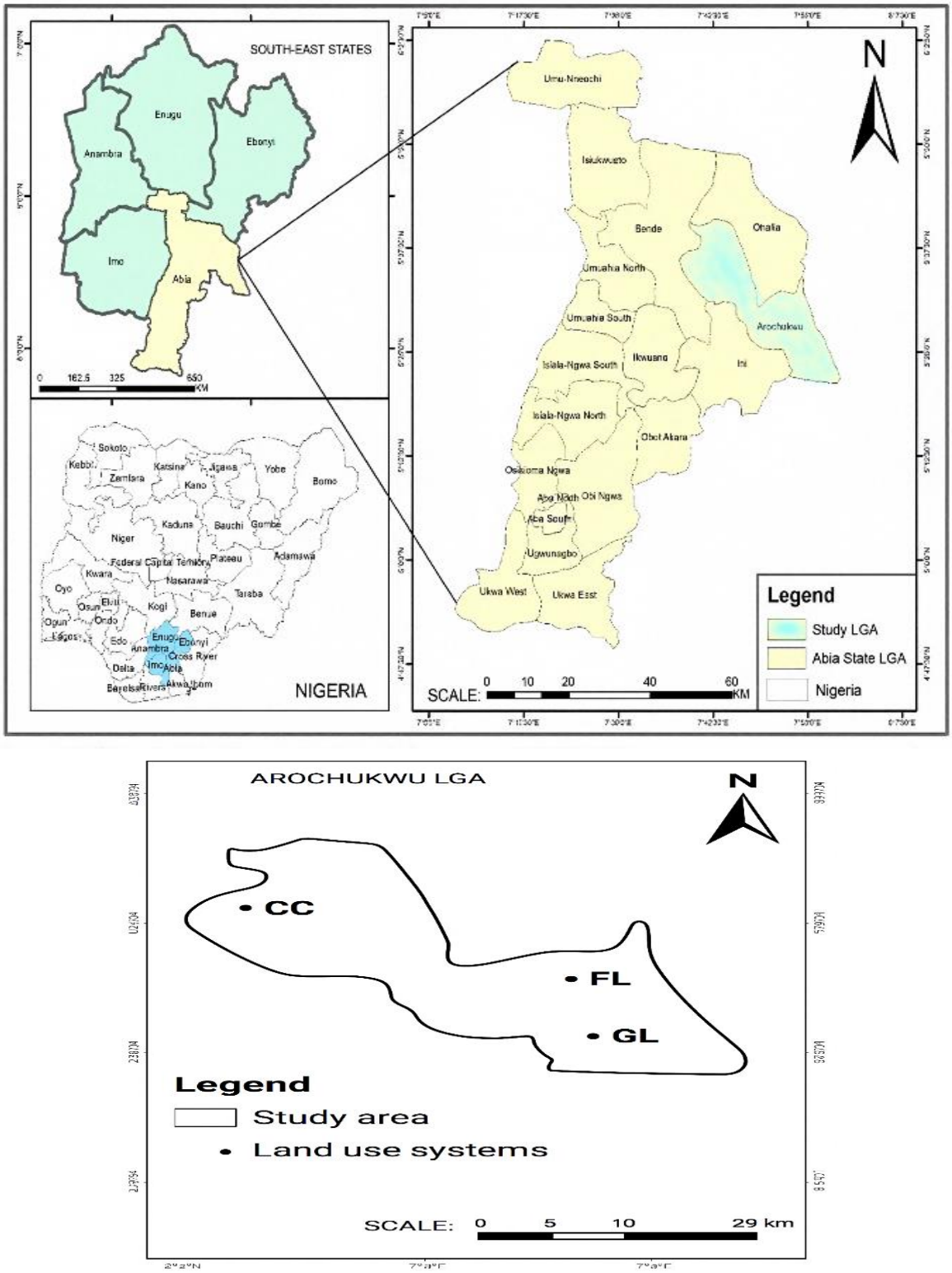


Fig. 1. Map of the study area (FL= forest land; CC= continuously cultivated land; GL= grass land).

2.5. Field study

For each of the three land-uses, six sampling points were selected at random and within the six points, three replicates were mapped out. The sampling points were re-selected randomly at every sampling event. At every sampling point within these land uses, soil core samples were collected from two depths: 0–20 cm and 20–40 cm in three replicates, to determine soil moisture. A total of 108 soil core samples were collected weekly over a 12-month period spanning January to December 2024. To collect the soil samples, using the method, soil cores were inserted vertically into the soil at 0–20 and 20–40 cm depths, making sure to minimize disturbance to the surrounding soil structure. The soil cores were extracted carefully from the soil place it into clean, labeled containers to avoid contamination and ensure adequate identification. Finally, the soil core samples were stored under cool and dry environments and then ready for soil moisture analysis. These samples supported ground-truthing, aimed at validating meteorological data sourced from the National Oceanic and Atmospheric Administration and the National Centers for Environmental Prediction. The validation process was conducted on a monthly basis.

2.6. Collection of climate data

Meteorological data for this research was sourced from the National Oceanic and Atmospheric Administration and the National Centers for Environmental Prediction (NOAA/NCEP, 2024), operating under the National Weather Service in the United States. The dataset, gathered via satellite over a one-year span from January to December 2024, was obtained through remote sensing and Geographic Information Systems (GIS). Hourly readings were aggregated into monthly values, focusing on key climate indicators such as rainfall, temperature, sunshine duration, and soil moisture.

2.7. Laboratory analysis

Soil moisture content was calculated using the gravimetric method where 18 soil samples were placed into ceramic crucibles and weighed to get the fresh weight and then oven-dried at 105 °C to constant weight for about 48 hours and the dry weight recorded (Jury and Horton, 2004). These values were then used to calculate the moisture contents of the soils using the Eq. 1:

$$\text{SMC (\%)} = \frac{(Wf - Wd)}{Wd} \text{ x } 100 \quad (1)$$

Where *SMC*= soil moisture content (%), *Wf*= fresh weight (g) of soil sample, *Wd*= dry weight (g) of soil sample.

This procedure was carried out to confirm the accuracy of soil moisture data acquired from the National Oceanic and Atmospheric Administration and the National Centers for Environmental Prediction (NOAA/NCEP), which operate under the United States National Weather Service.

2.8. Statistical analysis

The data was subjected to analysis of variance, and the resulting means were distinguished through the application of the least significant difference (LSD) method. Line graph was used to show the trend and variations of the climatic factors and soil moisture in the different land uses while regression analysis was employed to examine how soil moisture levels (remote-sensed data) correlate with various climatic conditions.

3. Results and discussion

3.1. Atmospheric temperature

Fig. 2 shows the variations in atmospheric temperature under three different land use systems - grass land (GL), continuously cultivated land (CC) and forest land (FL) - over a period of 1 year (12 months). The result shows how land use interacts with seasonal weather patterns in altering atmospheric temperature. At the start of the year during the dry season, atmospheric temperatures were highest across all land use systems, with January having the peak values: forest land recorded 28.63 °C, continuously cultivated land reached 29.38 °C, and grass land was at 28.32 °C. The elevated readings during this period could be attributed to clear skies, intense solar radiation, and limited rainfall (Echebima and Obafemi, 2023). Continuously cultivated land recorded the highest temperature of 29.38 °C in January. As the seasons transitioned into the rainy period from April to October, atmospheric temperature gradually decreased. The atmospheric temperature

slightly dropped in April, and by July (coinciding with the height of the rainy season) the atmospheric temperatures reached its lowest points: 25.04 °C in forest land, 25.82 °C in cultivated land, and 25.77 °C in grass land. This decline was primarily due to increased rainfall, persistent cloud cover, and high humidity, all of which limit solar heating (Ndakara and Eyefia, 2021). Moreover, vegetation thrives during this rainy season, especially in forest and grass land areas, enhancing evapotranspiration and further cooling the atmosphere (Wang et al., 2023). Forested areas remained the most thermally stable, while continuously cultivated land, though slightly cooler than during the dry season, retained higher heat levels because of its reduced vegetative cover. From September to December, as the rainy season waned, atmospheric temperature began to rise again. In December, atmospheric temperatures were relatively uniform across all land use systems: 27.44 °C in forest land, 27.60 °C in continuously cultivated land, and 27.78 °C in grass land. This convergence may have likely resulted from residual soil moisture and moderate cloudiness that reduced temperature (Ndakara and Eyefia, 2021). Forest land maintained lower temperatures than other land use systems owing to its dense canopy, which reduces solar penetration and supports moisture retention, thereby enhancing cooling through transpiration (Ni et al., 2019; Zhang et al., 2023). Lin et al. (2020) also observed that the thick vegetation in the forest acts as a thermal buffer thereby absorbing heat. The continuously cultivated land consistently exhibited the highest temperatures due to minimal vegetation cover, high surface exposure and regular soil disturbance, which increase heat absorption and reduce cooling effects (Steponavičienė et al., 2024).

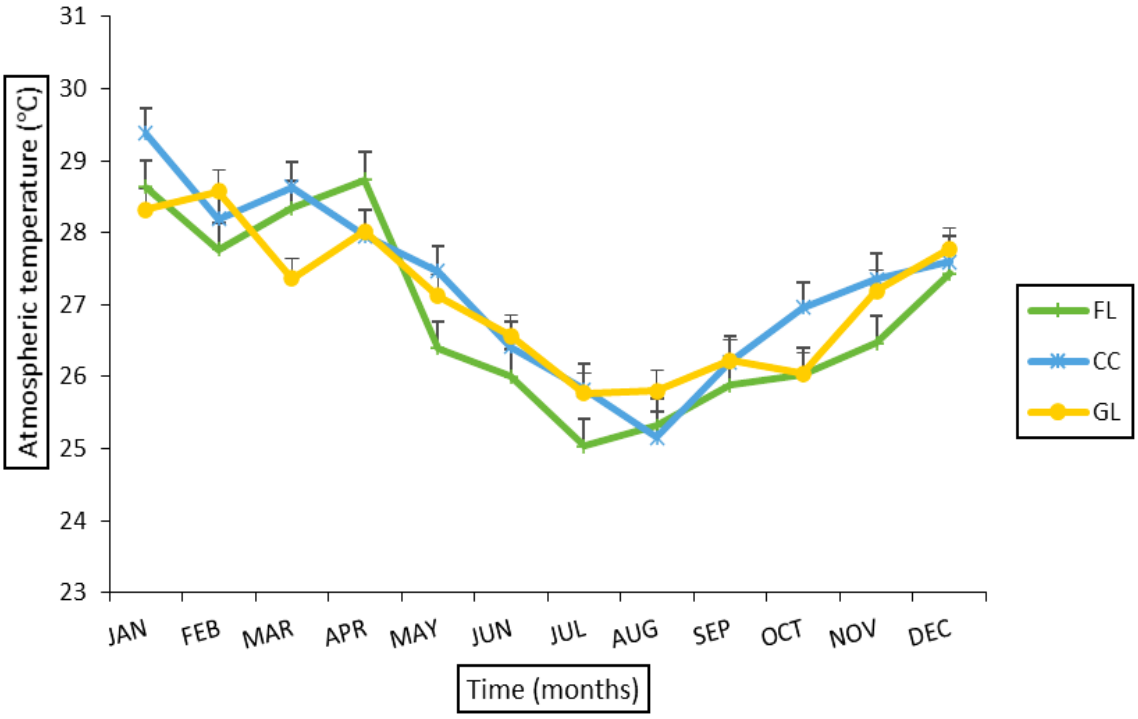


Fig. 2. Variability of atmospheric temperature under different land use systems. (FL= forest land; CC= continuously cultivated land; GL= grass land).

3.2. Rainfall

The result in Fig. 3 shows the monthly variation in rainfall distribution across grass land (GL), continuously cultivated land (CC) and forest land (FL) over a one-year period. The pattern strongly reflects the seasonal dynamics of a tropical climate, alternating between a dry season that stretches from January to March and extending from November to December and a wet season from April to October. During the dry months of the year, January to March and in December, monthly rainfall was exceptionally low across all land uses. In December, the lowest monthly rainfall was recorded, with cultivated land recording an

extremely low rainfall of 7.63 mm month^{-1}, while forest land and grass land were slightly higher at 25.04 mm month^{-1} and 9.20 mm month^{-1}, respectively. This period coincides with the peak of the dry season, when precipitation was sparse due to the dominance of dry northeasterly winds (Harmattan), reduced cloud formation, and intense evapotranspiration. Rainfall began to increase progressively from February into March, with forest land increasing from 113.09 mm month^{-1} to 169.06 mm month^{-1} and grass land following closely at 162.86 mm month^{-1} in March. This transition reflects the onset of the rainy season, triggered by the gradual northward shift of the Intertropical Convergence Zone (ITCZ), bringing moisture-laden southwest winds and resulting in more frequent thunderstorms and convective rainfall (Ibebuchi and Abu, 2023). An increase also occurred from April through July, which represents the core of the rainy season. July emerged as the wettest month overall, where forest land received its highest rainfall of 458.95 mm month^{-1}, continuously cultivated land followed at 444.67 mm month^{-1}, and grass land measures 442.70 mm month^{-1}. This surge can be attributed to the intensification of the ITCZ's influence, heightened atmospheric instability, and increased humidity, all of which promote sustained precipitation (Ndakara, and Eyefia, 2021). After July, rainfall began to decline but remained moderately high in August and September. This gradual decline reflects the retreat of the ITCZ and the tapering intensity of rainfall events. Grass land often showed a slightly delayed response to the seasonal shift, which might be due to its transitional vegetation cover and surface roughness that still support localized convective rainfall (Feng et al., 2023). October marked the onset of the dry transition, evident in the reduction of rainfall to 254.32 mm month^{-1} in forest land and 200.21 mm month^{-1} in cultivated land. November continued this downward trend, with values dropping to 110.47 mm month^{-1} in forest land and only 70.59 mm month^{-1} in grassland. This marks the end of the wet season and the beginning of another dry cycle. Throughout the year, forest land consistently recorded the highest or near-highest rainfall amounts. This can be attributed to its closed canopy structure, which enhances moisture recycling through evapotranspiration and promotes localized rainfall generation (De Frenne et al., 2019; Roberts, 2023). Continuously cultivated land had the lowest rainfall in most months, particularly in the dry season, where its exposed, tilled surfaces and limited vegetation reduce its capacity for moisture retention (Aderonke and Gbadegesin, 2013). Grass land generally exhibits rainfall patterns close to forested areas during peak wet months, likely due to its seasonal vegetation growth and intermediate landscape structure that helps trap and retain rainfall (Bond et al., 2020).

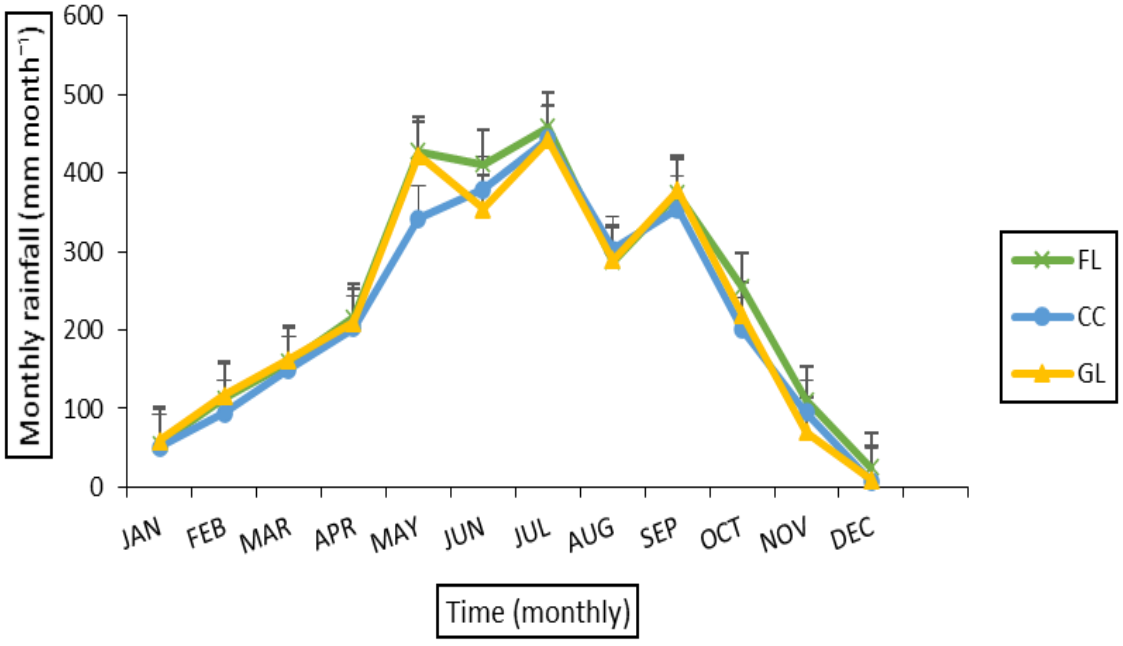


Fig. 3. Variability of rainfall under different land use systems. (FL= forest land; CC= continuously cultivated land; GL= grass land).

3.3. Sunshine duration

The monthly variation of sunlight duration across different land use systems; grass land (GL), continuously cultivated land (CC) and forest land (FL) is presented in Fig. 4. This result reflect how solar exposure varies not only with seasonal progression but also with differences in surface cover and land management. The dry season months, particularly January and December, showed the highest sunlight durations across all land uses. January, recorded 5.04 hours day^{-1} in continuously cultivated land, 4.52 hours day^{-1} in grass land, and 4.05 hours day^{-1} in forest land. This pattern corresponds with the clear skies of the harmattan period, when atmospheric dust may filter sunlight but cloud cover remains minimal, allowing substantial direct solar exposure (Abindaw et al., 2023). Continuously cultivated land recorded the highest values due to sparse vegetation and more open surfaces, which allow sunlight to reach the ground without much obstruction (Fahmi et al., 2026). Forest land consistently exhibited the lowest sunlight durations, a result of dense canopy cover that limits solar penetration to the forest floor (Zhang et al., 2023). As the transition into the rainy season began in March and deepened from April through July, there was a marked reduction in sunlight duration. This drop was most pronounced in forest land, where July recorded only about 2.02 hours day^{-1}. Hughes et al. (2024) noted that Increased cloudiness, frequent rain events, and enhanced vegetation growth may have contributed to this reduction in sunlight duration. Continuously cultivated areas and grass lands experienced similar decrease but remain slightly higher due to less canopy interference. July, typically the peak of the wet season, had the lowest sunshine duration, reflecting heavy rainfall and persistent cloud cover. From August through October, sunlight durations began to recover slightly. September and October marked the end of the peak rainy months, and as cloud cover began to thin, solar exposure increased. Continuously cultivated land still recorded slightly higher values, hovering above 2.8 hours day^{-1}, while forests remain the most shaded due to continued high vegetation density. As the dry season returns in November and December, sunlight duration rises sharply. This variation of sunshine duration in forest land could be attributed to forests acting as effective solar buffers (De Frenne et al., 2019). Abindaw et al. (2021), observed that in continuously cultivated land, due to its openness and lack of vertical vegetation, is more exposed to direct sunlight. Grass lands respond moderately, offering a balance between solar capture and shading depending on seasonal greenness and biomass density.

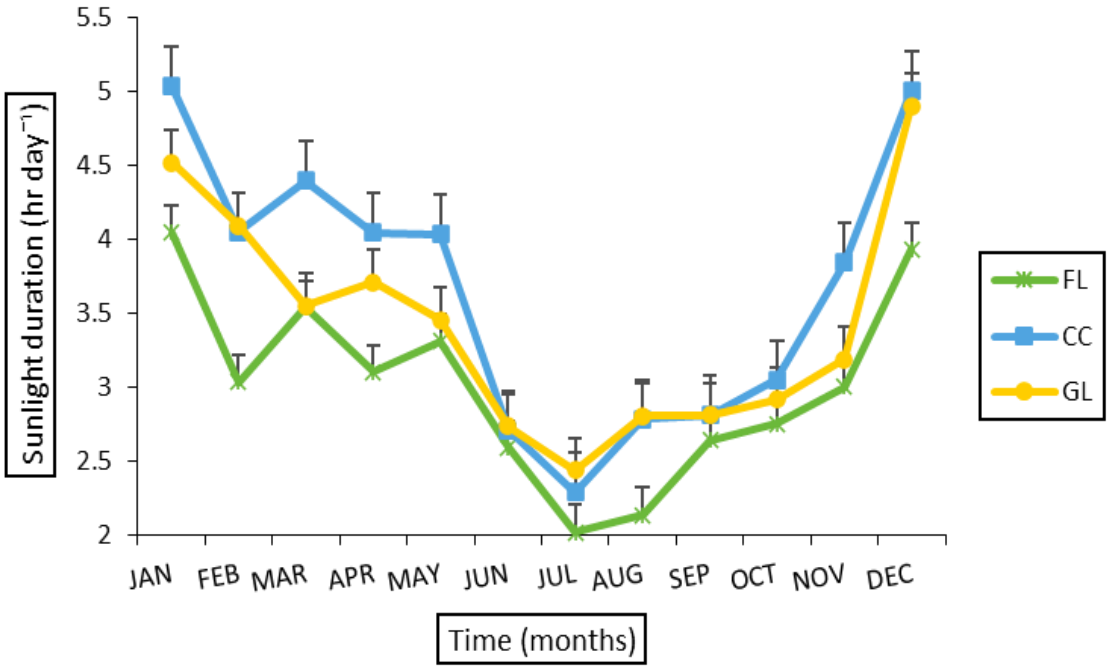


Fig. 4. Variability of sunshine duration under different land use systems. (FL= forest land; CC= continuously cultivated land; GL= grass land).

3.4. Soil moisture 0–20 cm

Fig. 5 displays the monthly variations in soil moisture content (0–20 cm) across grass land, continuously cultivated land, and forest land. In the early part of the year (January and February) soil moisture were relatively low across all systems, with cultivated land having the lowest at 0.18 kg kg^{-1} and 0.42 kg kg^{-1} respectively. These months coincide with the heart of the dry season, when rainfall was minimal and evapotranspiration was high. Forest and grass lands retained more moisture during this period, probably due to better vegetative cover and lower direct soil exposure. Forest soils benefit from shading and thick organic layers that preserve moisture, while grass land, though more open, still supports seasonal grasses that reduce evaporation (Wang and Liu, 2023). As the transition toward the rainy season began in March, soil moisture increased substantially, especially in forest land and continuously cultivated land, reaching peaks of 1.52 kg kg^{-1} and 1.25 kg kg^{-1}, respectively. This rise continued into April, supported by increasing rainfall, although the forest still maintained higher levels than continuously cultivated land. The consistently lower moisture in continuously cultivated land throughout this period reflects its vulnerability to runoff, shallow rooting systems, and regular tillage, which disrupt soil structure and infiltration (Oguike and Onwuka, 2018). From May through July, soil moisture content in forest and grass lands remained moderately high, supported by sustained rainfall and the water-retaining properties of healthy soil ecosystems. Continuously cultivated land dipped in June and July despite these conditions, likely due to poor water retention capacity and reduced organic matter that cannot hold moisture effectively (Alhassan and Audu, 2024). A notable peak occurred in August, where forest land recorded its highest moisture content at 1.88 kg kg^{-1}. This surge aligned with intense rainy season activity and the forest's remarkable capacity for moisture accumulation (Alo et al., 2022). Grass land also experienced a rise, while cultivated land improved slightly but still trailed behind. As the rainy season waned through September and October, soil moisture gradually declined but remained fairly high, especially in forest and grass lands. Continuously cultivated land showed very little fluctuation, maintaining consistently lower values, which may be due to rapid drainage and reduced soil structure. By November and December, all land use systems showed a decline, reflecting the return of the dry season. However, forest and grass land still retained higher moisture than cultivated land. Forest and grass lands generally maintained higher soil moisture levels than continuously cultivated land. This was likely due to the increased vegetation cover and root activity in forest land and grassland, which enhance soil water retention and reduce evaporation (Adane et al., 2018). Also, forest and grass lands have improved soil structure, which may have played a role in increasing water-holding capacity Adekiya et al. (2021).

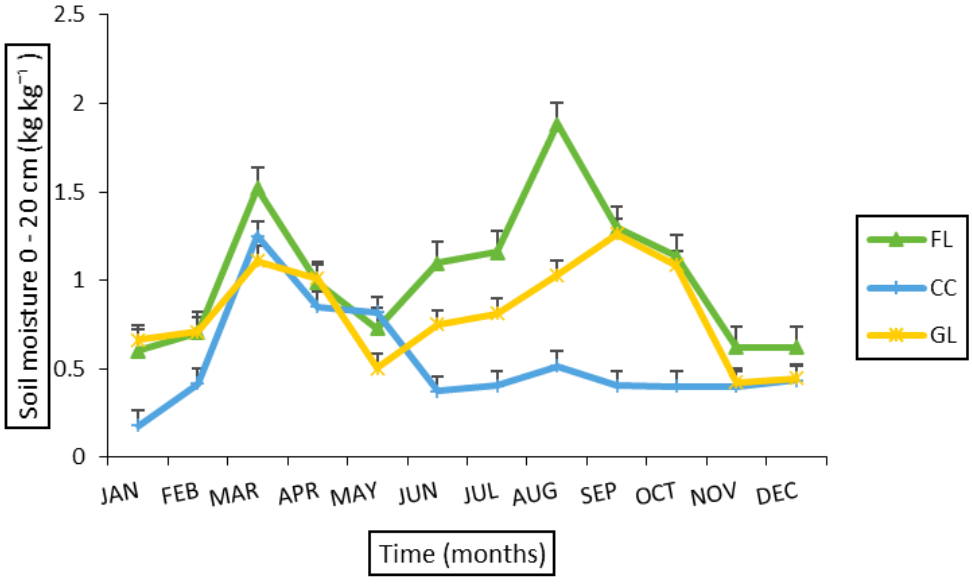


Fig. 5. Variability of soil moisture 0 – 20 cm under different land use systems. (FL= forest land; CC= continuously cultivated land; GL= grass land).

3.5. Soil moisture 20–40 cm

The monthly variation in soil moisture content (20–40 cm) across forest land, continuously cultivated land, and grass land is presented in Fig. 6. From the early dry season months of January and February, soil moisture was at its lowest, especially in continuously cultivated land, which began at 0.12 kg kg^{-1} and reached 0.19 kg kg^{-1} in February. This limited moisture retention was likely due to exposed soil surfaces and reduced vegetation cover, which accelerate evaporation and reduce infiltration. However, forest land, with its shaded floor and litter layer, and grassland, supported by seasonal groundcover, maintain higher moisture levels during this same period. Forest land had 0.43 kg kg^{-1} in January and increased slightly in February, while grass land, notably, showed a spike in February to 0.42 kg kg^{-1}, possibly due to residual water retention following minor seasonal showers or due to the subsurface buffering effect of fibrous roots (Adewole et al., 2024). With the onset of the wet season around March and its intensification in April, all land use systems showed significant increase in subsoil moisture. Forest land rose to 1.29 kg kg^{-1} in April, due to enhanced infiltration, increased rainfall, and reduced surface runoff as a result of dense vegetation and deep root systems (Adigarla et al., 2025). Grass land reached 1.18 kg kg^{-1} in April, showing its effective water holding capacity as rainfall peaks. Continuously cultivated land improved during this period but remains comparatively limited, reaching only 0.45 kg kg^{-1}, which may be due to tillage, shallow rooting, and compacted topsoil continue to restrict moisture percolation (Nurudeen, 2023). In May, soil moisture content fell slightly across all land uses, likely reflecting a short dry spell or increased evapotranspiration, but the recovery continued through June and July with a secondary peak. July showed high soil moisture content, with forest land at 1.16 kg kg^{-1} and grass land at 1.21 kg kg^{-1}, indicating that both land uses are saturated during the heart of the rainy season. Continuously cultivated land showed a delayed peak at 0.89 kg kg^{-1} in July, benefiting from accumulated rainfall but still lagging behind due to soil disruption and lower organic content. August introduced a general decline in moisture levels as the rainy season began to decrease. Forest and grass lands held moisture at 0.92 kg kg^{-1} and 0.62 kg kg^{-1} respectively, while cultivated land had another sharp drop. By September and October, moisture levels began to stabilize, although at reduced levels, reflecting reduced rainfall and the beginning of the dry transition. In the final months of the year (November and December) there was a steady decline across the land uses. Forest land closed the year at 0.48 kg kg^{-1}, grassland at 0.38 kg kg^{-1}, and continuously cultivated land at 0.25 kg kg^{-1}.

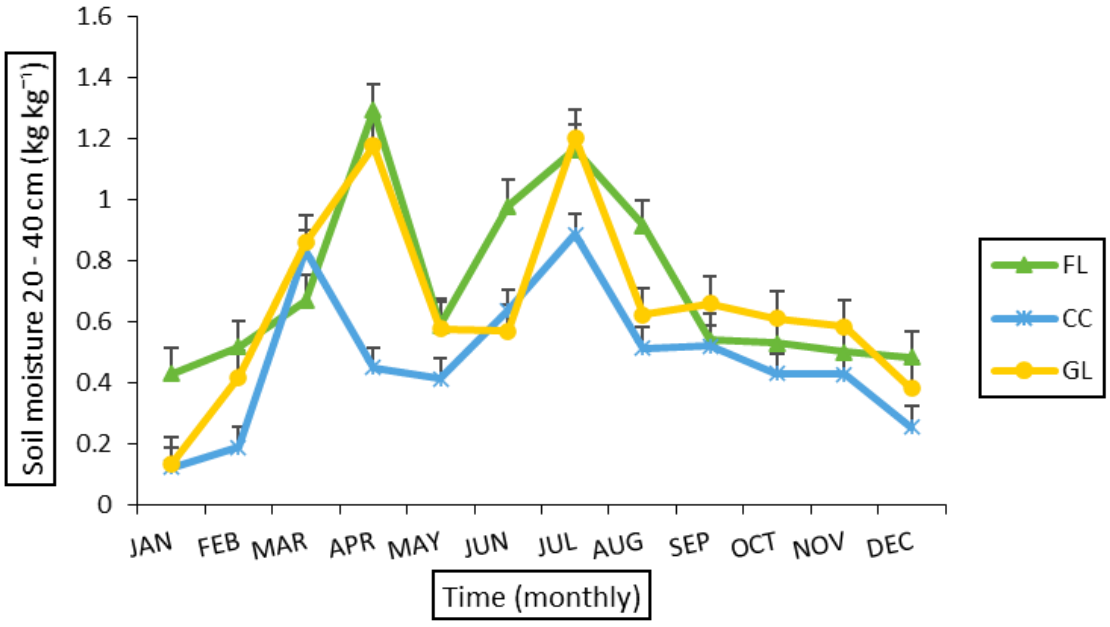


Fig. 6. Variability of soil moisture 20–40 cm under different land use systems (FL= forest land; CC= continuously cultivated land; GL= grass land).

3.6. Relationship between soil moisture and rainfall

Fig. 7 illustrates the regression analysis of rainfall and soil moisture content at 0–20 cm. The result revealed the relationship between rainfall and soil moisture content, represented by the regression equation (SMC = 0.002RF + 0.1404). The slope of the regression line was 0.002, which means that for every 1 mm increase in rainfall, the soil moisture content increased by 0.002 kg kg^{-1} on average. The intercept of the regression line was 0.1404, which implies that when the rainfall was zero, the soil moisture content was 0.1404 kg kg^{-1}. The relationship recorded a coefficient of determination (R^2) of 0.6849, indicating that the model explains 68.49% of the variation in soil moisture content based on rainfall. The findings of the study indicate that rainfall had a strong relationship with soil moisture. The finding shows that as the amount of rainfall increases, so does the soil moisture, and vice versa. This relationship can be attributed to the fact that rainfall serves as the primary source of water for the soil. Once introduced, the water is retained in soil pores and adheres to the surfaces of soil particles. Soil moisture essentially represents the volume of water accessible for plant development and other biological functions. According to Zhu et al. (2022), this connection is influenced by factors that regulate both water infiltration and evaporation within the soil matrix. Further emphasized that increased precipitation enhances water infiltration rates, thereby boosting soil moisture content.

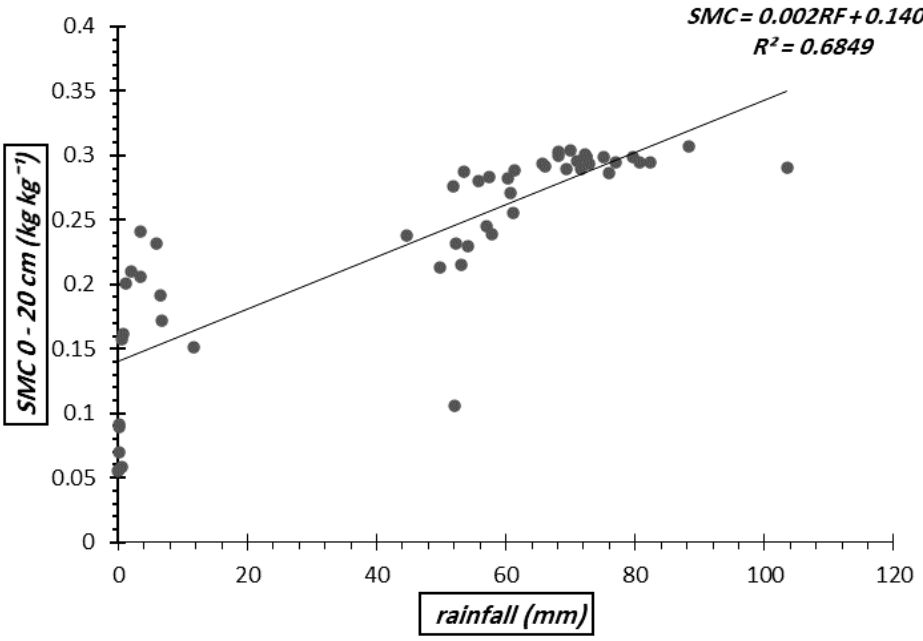


Fig. 7. Regression analysis between rainfall and soil moisture content.

3.7. Relationship between soil moisture and atmospheric temperature

Fig. 8 displays the regression analysis between atmospheric temperature and soil moisture content at 0-20 cm. The analysis revealed a negative linear relationship, modeled by the equation SMC = -0.05TEMP + 1.5508. This indicates that each 1 °C rises in temperature corresponds to an average decline of 0.05 kg kg^{-1} in soil moisture. The intercept of the regression line was 1.5508 implying that at a temperature of 0 °C, the soil moisture content would be 1.5508 kg kg^{-1}. The R^2 value of 0.5332 indicates that the model explains 53.32% of the variation in soil moisture based on temperature. The result highlights a significant inverse association between atmospheric temperature and soil water content. In other words, increases in temperature are generally linked to a drop in soil moisture, and the reverse. This trend may be explained by higher temperatures accelerating the evaporation of water from the soil surface, thereby reducing moisture levels (Meng et al., 2024). Tang et al. (2023) further noted that elevated temperatures can impact plant growth and transpiration, which in turn affect soil water availability. Conversely,

cooler conditions allow more water to remain in the soil. Additionally, Berg et al. (2014) emphasized that temperature influences the vertical distribution of moisture across various soil layers.

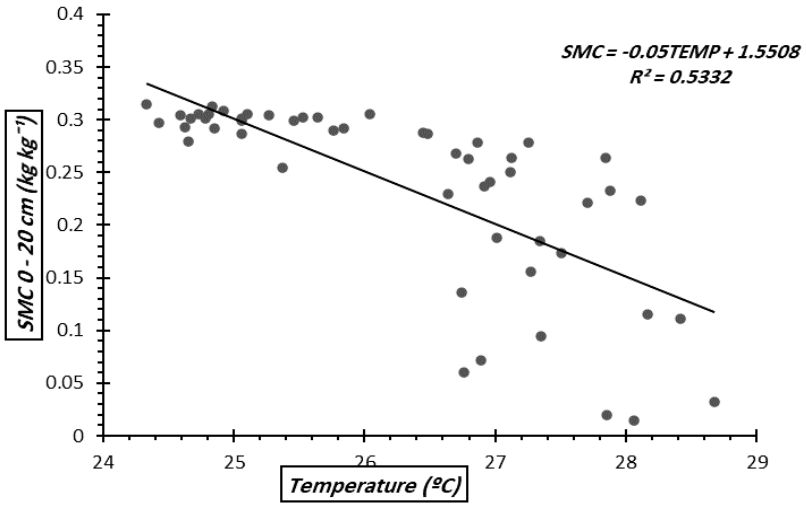


Fig. 8. Regression analysis between atmospheric temperature and soil moisture content.

3.8. Relationship between sunshine duration and soil moisture

The result in Fig. 9 presents a regression plot examining how sunshine duration correlates with soil moisture at 0–20 cm. The relationship is modeled by the equation SMC = -0.076SD + 0.4602, indicating a negative slope of -0.076. This means that an increase of one hour per day in sunlight duration results in an average reduction of 0.076 kg kg^{-1} in soil moisture content. The intercept, valued at 0.4602, reflects the expected soil moisture level when sunlight duration is zero. With a coefficient of determination (R^2) of 0.7905, the model explains 79.05% of the variation in soil moisture in relation to sunshine duration.

From the study it was induced that sunlight duration and soil moisture had a negative relationship, which can be attributed to evaporation, precipitation, and plant transpiration. Hassanpour Adeh et al. (2018) observed that the longer the sunlight duration, the higher the evaporation rate, and the lower the soil moisture. This can lead to drought conditions and reduced crop yields. The longer the sunlight duration, the higher the transpiration rate, and the lower the soil moisture. This can also affect plant growth and water availability.

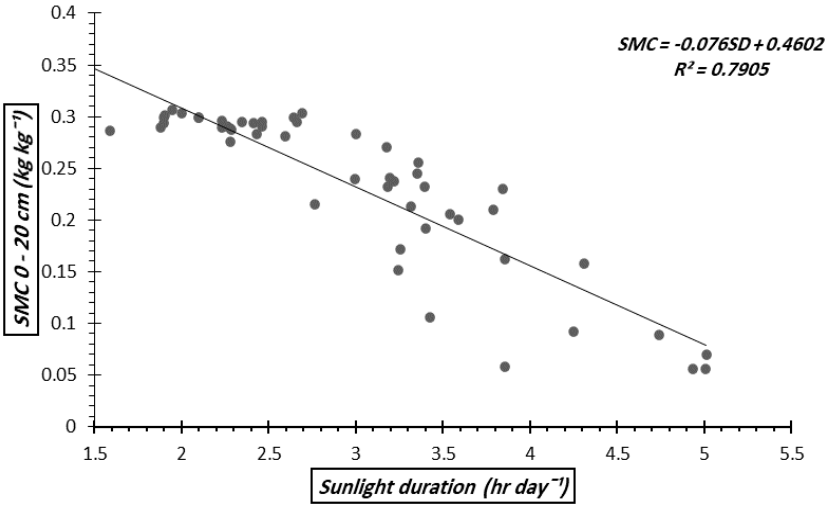


Fig. 9. Regression analysis between sunlight duration and soil moisture content.

4. Conclusion

This study assessed the variability of soil moisture under different land use systems (forest land, continuously cultivated land and grass land) and its relationship with climate within a tropical zone. The result showed significant differences in soil moisture across the land use systems. The study demonstrate that land use systems significantly influenced atmospheric temperature, with continuously cultivated land recording higher temperatures than forest and grass land. The study showed that with forest land maintained higher soil moisture levels than continuously cultivated and grass land. The results also present that land use systems significantly influenced sunlight duration, with continuously cultivated land recording longer sunlight duration than forest and grass land. Soil moisture had a negative relationship with atmospheric temperature and sunlight duration, and also had a strong positive relationship with rainfall. This work is relevant because it explains how land use systems directly affect soil moisture dynamics and local climate patterns, providing knowledge for sustainable land management and climate adaptation strategies in tropical regions. However, the study's scope was limited by focusing only on limited sampling points with few land use systems and climatic variables, leaving out other potential drivers such as soil texture, vegetation diversity, and human management practices. Future research could expand to long-term monitoring across varied land use systems and integrate remote sensing with field data to strengthen predictions and inform broader climate resilience policies. By understanding the relationships between land use, soil moisture and climate patterns, policymakers and land managers can make informed decisions to optimize land use and promote climate resilience.

Acknowledgments

The authors express their gratitude to the National Oceanic and Atmospheric Administration and the National Centers for Environmental Prediction (NOAA/NCEP), operating under the U.S. National Weather Service, for their valuable data support. All expenses and financial backing for the project were solely provided by the authors.

References

Abindaw, T., Hanyabui, E., Atiah, K., Akwasi, E. A. & Ziblim, I.A., 2023. Influence of land use types on the distribution of selected soil properties in tropical soils of the Coastal Savanna zone. *Heliyon*, 9(3), e14002.

Adane, Z.A., Nasta, P., Zlotnik, V. & Wedin, D., 2018. Impact of grassland conversion to forest on groundwater recharge in the Nebraska Sand Hills. *Journal of Hydrology: Regional Studies*, 15, 171-183.

Adekiya, A.O., Aremu, C., Agbede, T.M., Olayanju, A., Ejue, W.S., Adegbite, K.A. & Oni, A.T., 2021. Soil productivity improvement under different fallow types on Alfisol of a derived savanna ecology of Nigeria. *Heliyon*, 7(4).

Aderonke, D.O. & Gbadegesin, G.A., 2013. Spatial variability in soil properties of a continuously cultivated land. *African Journal of Agricultural Research*, 8(6), 509–519.

Adewole, A.O., Eludoyin, A.O., Chirima, G.J. & Newete, S.W., 2024. Field-scale variability and dynamics of soil moisture in Southwestern Nigeria. *Discover Soil*, 1, Article 12.

Adigarla, Y.N., Singh, S., Sreelash, K., Srivastava, H.S. & Nikam, B.R., 2025. Contributions of meteorological and vegetation factors to surface and root zone soil moisture variability across India's agro-ecological regions. Remote Sensing Applications: *Society and Environment*, 40, 101803.

Alhassan, I. & Audu, S., 2024. Influence of land use on spatio-temporal variation in soil moisture in a Sahel area of North East Nigeria. *Bulgarian Journal of Soil Science*, 9(1), 45–58.

Alo, A.A., Agbor, C.F., Jebiwott, A. & Temiloluwa, O., 2022. Spatial distribution of soil moisture content and tree volume estimation in IITA Forest, Ibadan, Nigeria. *Journal of Geoscience and Environment Protection*, 10, 364–384.

Araya, S.N., Mitchell, J.P., Hopmans, J.W. & Ghezzehei, T.A., 2022. Long-term impact of cover crop and reduced disturbance tillage on soil pore size distribution and soil water storage. *Soil*, 8(1), 177–198.

Berg, A., Lintner, B.R., Findell, K. L., Malyshev, S., Loikith, P.C. & Gentine, P., 2014. Impact of soil moisture–atmosphere interactions on surface temperature distribution. *Journal of Climate*, 27(21), 7976-7993.

Bond, S., Kirkby, M.J. & Holden, J., 2020. Seasonal vegetation and management influence overland flow velocity and roughness in

upland grasslands. *Hydrological Processes*, 34(15), 3301–3315.

City population., 2024. The population development in Abia as well as related information and services. *https://www.citypopulation.de/php/nigeria-admin.php?adm1id=NGA001*. Accessed March 6th, 2024.

De Frenne, P., Zellweger, F. & Rodríguez-Sánchez, F., 2019. Global buffering of temperatures under forest canopies. *Nature Ecology & Evolution*, 3(5), 744–749.

Echebima, S.I. & Obafemi, A.A., 2023. The influence of local rainy and dry seasons on the diurnal temperature range in Nigeria. *Atmospheric and Climate Sciences*, 13(2), 314–332.

Fahmi, M., Achmad, A., Husin, H. & Dewi, C., 2026. Investigating land surface temperature (LST) and its influencing factors in the Laut Tawar sub-watershed, Indonesia, using Landsat 9 data. *Sustainability*, 18(1), 96.

Feng, S., Zhang, Z., Zhao, S., Guo, X., Zhu, W. & Das, P., 2023. Time lag effect of vegetation response to seasonal precipitation in the Mara River Basin. *Ecological Processes*, 12, Article 49.

Hassanpour Adeh, E., Selker, J.S. & Higgins, C.W., 2018. Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency. *Plos One*, 13(11), e0203256.

Hughes, N.M., Sanchez, A., Berry, Z.C. & Smith, W.K., 2024. Clouds and plant ecophysiology: Missing links for understanding climate change impacts. *Frontiers in Forests and Global Change*, 7, Article 1330561.

Ibebuchi, C.C. & Abu, I.-O., 2023. Rainfall variability patterns in Nigeria during the rainy season. *NOAA Institutional Repository*. https://repository.library.noaa.gov/view/noaa/64822/noaa_64822_DS1.pdf

Ideozu, R., James, P.O. & Eke, C.M., 2019. Biostratigraphy and depositional environment of the Pebble Belt area, southeastern Nigeria. *SF Journal of Environmental and Earth Science*, 2(1), 1–14.

John, U.J., Igboekwe, M.U. & Amos-Uhegbu, C., 2015. Geophysical evaluation of erosion sites in some parts of Abia State, Southeastern Nigeria. *Physical Science International Journal*, 6(2), 66-81.

Jury, W.A., & Horton, R., 2004. Soil Physics. *John Wiley & Sons*, 5.

Kaur, G. & Kaur, S., 2017. Precipitation: Changing patterns, crop effects and mitigation: A brief review. *International Journal of Research in Geography*, 3(1), 26–32.

Koelemeijer, I.A., Severholt, I., Jönsson, M., Ehrlén, J., De Frenne, P. & Hylander, K., 2024. Canopy cover and soil moisture influence forest understory plant responses to experimental summer drought. *Global Change Biology*.

Lin, H., Tu, C. & Fang, J., 2020. Forests buffer thermal fluctuation better than non-forests. *Agricultural and Forest Meteorology*, 288–289, 107994.

Meng, Q., Liu, J., Chen, P., Xu, J., He, Q., Cidan, Y. ... & Huang, Y., 2026. Nonmonotonic Elevational Patterns of Soil CO2 Flux Driven by Temperature Dominance and Moisture Thresholds in the Sejila Mountains, Tibetan Plateau. *Forests*, 17(3), 390.

Ndakara, O.E. & Eyefia, O.A., 2021. Spatial and seasonal variations in rainfall and temperature across Nigeria. *Journal of Biodiversity and Environmental Sciences*, 18(2), 79–92.

Ni, J., Cheng, Y., Wang, Q., Ng, C.W.W. & Garg, A., 2019. Effects of vegetation on soil temperature and water content: Field monitoring and numerical modelling. *Journal of Hydrology*, 571, 494-502.

NOAA/NCEP, 2024. National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction (NCEP) Global weather Forecast System (GFS) Atmospheric Model. Climate data distributed by the Pacific Islands Ocean Observing System (PacIOOS). *National Weather Service, USA. http://pacioos.org/metadata/ncep_global.html*.

Nurudeen, O.O., 2023. Soil physical properties, organic carbon dynamics, and maize performance under long-term grazing and continuous cultivation in Ado Ekiti, Nigeria. *International Journal of Agricultural Research and Development*, 20 (1), 36-42.

Oguike, P.C. & Onwuka, B.M., 2017. Variations in texture, water retention and transmission, organic matter and pH of Soils under Selected Land Use Systems at Ubakala Umuahia, South-Eastern Nigeria. *Journal of Scientific and Engineering Research*, 4(7), 147-155.

Oguike, P.C. & Onwuka, B.M., 2018. Moisture characteristics of soils of different land use systems in Ubakala Umuahia, Abia State, Nigeria. *International Journal of Scientific and Research Publications*, 8(4), 17–24.

Roberts, J.M., 2023. The role of forests in the hydrological cycle. *EOLSS – Encyclopedia*

of Life Support Systems. *https://www.eolss.net/Sample-Chapters/C10/E5-03-04-02.pdf*

Shahen, M.A., Islam, M.F., Al Amin, M., Rahman, A., Akter, S., Rahman, M.M. & Hossain, M.M., 2026. Assessing the impact of climate change on land fertility and pesticide usage: A study of farming practices in Northern Bangladesh. *Environmental Challenges*, 24, 101558.

Singh, R. & Kumar, A., 2023. Anthropogenic stress and climate variability: Implications for soil water balance and fertility in South Asia. *Catena*, 229, 107095.

Spadotto, C.A. & Mingoti, R., 2023. Climates, soils, and agriculture in the tropical region. Embrapa Agriculture Digital. https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1154854/1/PL-Climates-soils-agriculture-2023.pdf

Steponavičienė, V., Žiūraitis, G., Rudinskienė, A., Jackevičienė, K. & Bogužas, V., 2024. Long-term effects of different tillage systems and their impact on soil properties and crop yields. *Agronomy*, 14(4), 870.

Tang, M., Liu, R., Li, H., Gao, X., Wu, P. & Zhang, C., 2023. Optimizing soil moisture conservation and temperature regulation in rainfed jujube orchards of China's Loess hilly areas using straw and branch mulching. *Agronomy*, 13(8), 2121.

Wang, F., Xiao, S., Qian, H., Qiang, Z., Fen, H. & He, Z., 2023. Evapotranspiration characteristics of forest and grass vegetation and its response to environmental factors on the Loess Plateau. *Science Discovery*, 11(6).

Wang, X. & Liu, L., 2023. The impacts of climate change on the hydrological cycle and water resource management. *Water*, 15(13), 2342.

Wu, S., Wei, Z., Li, X. & Ma, L., 2023. Land–atmosphere coupling effects of soil temperature and moisture on extreme precipitation in the arid regions of Northwest China. *Frontiers in Earth Science*, 10, Article 1079131.

Zhang, Y., Feng, X., Chang, X. & Tie, L., 2023. Impacts of canopy structure on the sub-canopy solar radiation under a deciduous forest based on fisheye photographs. *Research in Cold and Arid Regions*, 15(3), 150–160.

Zhu, G., Yong, L., Zhao, X., Liu, Y., Zhang, Z., Xu, Y. ... & Wang, L., 2022. Evaporation, infiltration and storage of soil water in different vegetation zones in the Qilian Mountains: a stable isotope perspective. *Hydrology and Earth System Sciences*, 26(14), 3771-3784.