Research Article

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Evaluation of soil moisture in relation to climate variability across Umudike, South eastern Nigeria

Abstract

The evaluation of soil moisture in relation to climate variability was carried out in Umudike, Abia state. The objective of the study was to evaluate the relationship between soil moisture and climatic parameters in Umudike. Moisture content (MC) was calculated using the gravimetric method. Daily meteorological data used for this study were obtained from the National Oceanic and Atmospheric Administration/National Centre for Environmental Prediction (NOAA/NCEP) under the National Weather Service, United States of America. The data were transformed subjected to regression analysis which was used to compare the influence of climate variables on the measured soil heat transfer over a period of time. Relative humility showed about 86.31% control over the variations of soil moisture which means it has a strong, positive influence on the variation of soil moisture content. Rainfall exhibited a significant positive impact, with approximately 69.04% control over soil moisture variations, indicating that increased rainfall leads to higher soil moisture levels. Sunlight duration played a vital role, showing a 57.43% influence in reducing soil moisture content as sunlight duration increased. In contrast, wind speed had 1.01% which is a very weak negative impact, with little to no significant effect on soil moisture content. These results provide an understanding of the interplay between climatic variables and soil moisture, offering valuable insights for environmental and agricultural practices. The study recommends encouraging sustainable land use and conservation practices, like mulching and organic manure application, can help mitigate soil moisture loss. Diversifying crops to include those less sensitive to soil moisture variations can enhance resilience.

Keywords: soil moisture, climate variations, regression analysis, hydrology

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Introduction

Climate is defined as the "average weather", where weather consists of surface variables such as precipitation, temperature and wind, and the averaging period is classically 30 years.[1] The climate is not constant, it varies over time. One of such terms used to describe variations in climate is climate variability. Climate variability refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for a shorter period of time, such as a month, season or a year.[2] Such change in climate within a smaller time frame (monthly, seasonal or yearly), could result from natural variability or as a result of human activities.[3]

Precipitation is the major component of weather through which water is added to the soil surface.[4] Part of the water added to the soil as rainfall or snow melt flows down vertically through infiltration and is either held within the root zone for crop use or lost to underground water bodies and some of it is made available to plants while some is lost on the surface as run-off causing soil discharge and nutrient loss to streams and surface water.[5] Precipitation is a major source of soil moisture. Soil moisture refers to the water that is held between the pore spaces of the soil. It is the water that is in the vadose zone between the soil surface and the water table.[6] Although the amount of soil water is small compared to other components of the hydrological cycle, it is nevertheless important to many agronomic, hydrological, ecological and environmental processes.[7] Government agencies and private companies working on weather and climate, estimating the risk of run-off and soil erosion, flood control, and water quality require detailed knowledge of soil water status.[8] Soil moisture limits crop productivity in the semi-arid region as seasonal moisture in the rooting zone of crops is often inadequate to meet the crop demand for adequate biomass production and yield.[9] Estimating soil water status is a very important aspect of crop yield modeling.[10] Many agricultural management decisions such as irrigation scheduling, fertilization and pesticide-use optimization and rate of application, drainage system design, soil conservation system such as zero or reduced tillage, cropping system types, require prior knowledge of soil water status.[11] Field based hydrological or ecological research requires accurate measurement of soil moisture.

The understanding of climate variability and soil moisture dynamics is essential in accessing soil aeration, combating soil erosion, understanding movement of nutrients from the soil to plant roots, toxic substance concentration and microbial activity in the soil. Because of its importance for proper growth and development of a crop, it is also an important piece of information with respect to agriculture. Knowledge of root zone moisture content is useful for irrigation scheduling (Starr, 2015) and crop yield interpretation.[9] Because of the critical role of climate variability and soil moisture in crop management and hydrology, this study will be undertaken to assess the response of soil moisture dynamics to climate variability. The objective of this study was to evaluate the relationship between climate variables and soil moisture. in Umudike

Material and methods

Study area

The study site is located at Umudike in Ikwuano Local government area of Abia State, Nigeria. The area falls within within latitudes $5^0 20'$- $5^0 29'$N and longitudes $7^0 32'$ - $7^0 37'$E.[12] It is highly populated, with an average population density of 2100 inhabitants per square kilometre and a total area of 198km^2.[12] The location has a mean annual rainfall of 2201.92mm (Nigeria Meteorological Agency, 2015). The rainfall is bimodal, starts in April and ends in October with peaks in June and September.[13] Ikwuano local government area is underlain by the Benin Formation (Chukwu and Ajuamiwe, 2013). This Benin Formation is the coastal plain sands of Pleistocene age which is composed of fine-coarse grained sands and sandstone. In some places, insignificant layers of dense shale consisting of quartz and little feldspar are observed.[14]

Climate

Abia State is located within the tropical rainforest belt. The climate is typically hot humid tropical with a mean annual rainfall of about 3000 mm.[13] The mean annual temperature is generally uniform, ranging from 26^o C to 28^o C.[13] The climate is divided into the wet season (April to October) and dry season (November to March). The rainy season is characterized by bimodal rainfall pattern with peaks occurring in July and September and short dry spell of about three weeks between the peaks known as the August break (Nigeria Meteorological Agency, 2015). Relative humidity varies between 75 and 90 %.

Vegetation and soils

Abia state lies within the rain forest area of the country which has been almost completely replaced by secondary forest of predominantly rubber plantation and oil palm trees of various densities of coverage inter-mixed with tall grasses, herbaceous and woody shrubs such as *Chromolaena odorata* (Siam weed). The area is geomorphologically low-lying, tropical rainforest with moderately high plains and wooded savanna in some places. It has an average elevation ranging from 120 to 180 m above sea level.[15] Abia state is characterized by a great variety of landscapes ranging from rolling hills to dissected escarpments, and has major geomorphologic regions (plains and lowlands) such as the Niger River Basin and the Delta; the Coastal plain and the Cross-River basin; and the plateau and the escarpment.[16] Farming is done at subsistence level with traditional tools like hoes and machetes. Food crop cultivation dominates the agricultural landscape. The conservation practices include shifting cultivation that involves a one-season cropping followed by a two to four years bush fallow period, multiple cropping, cover cropping, mulching and organic manure application. Due to financial constraints of the resource- poor farmers, inorganic fertilizer application is rarely practiced.

Geology

The area is composed of clay, sand, sand rocks. The soils of Umudike were derived from semi consolidated sand and sandy clay deposits with occasional intercalation of shale and sandstone fragments at varying depths (Ahaiwe *et al*., 2010).

Climate data collection

Daily meteorological data used for this study was obtained from the National Oceanic and Atmospheric Administration/National Centres for Environmental Prediction (NOAA/NCEP) under the National Weather Service, United States of America.[17] The data was collected using the nonhydrostatic mesoscale weather and multi-scale weather models for a period of one year (12 months). The period of data collection comprised of the wet and dry seasons of the year. The period of collection was from July 1, 2022 to June 30, 2023. This was actualized using the geographic information system (GIS). The climate parameters measured include the following: temperature, relative humidity, sunshine duration, wind speed, rainfall and soil moisture content.

Field method

From the location, arable land was selected for the study. In the arable land, five sampling points were located randomly. At each of the five sampling points, soil core samples were collected for the determination of soil moisture content. This was done for ground-truthing (to compare with the meteorological data obtained from the National Oceanic and Atmospheric Administration/National Centres for Environmental Prediction.

Laboratory analysis

Soil moisture analysis was done in the laboratory to validate the values of soil moisture content obtained from the National Oceanic and Atmospheric Administration/National Centres for Environmental Prediction (NOAA/NCEP) under the National Weather Service, United States of America.

Moisture content (MC)

Moisture content (MC) was calculated using the gravimetric method where 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 hrs and the dry weight recorded. These values were then used to calculate the moisture contents of the soils using the formula:

$$MC\ (\%) = (fw - dw)/dw \times 100$$

where *MC* soil moisture content (%), *fw* fresh weight (g) of soil sample, *dw* dry weight (g) of soil sample.

Statistical analysis

The data generated were subjected to regression analysis which was used to evaluate the relationship between climate variables and soil moisture.

Results and discussion

Climatic variables

The climate data of the location under study is shown in Table 1. The table shows that the mean temperature was highest (28.7 ^{0}C) in the month December, 2022 whereas the month, July, 2023 had the lowest (25.0 ^{0}C) mean temperature. However, from February to May and October to December, the mean temperature was fairly constant. The location under study had experienced more than 25.0 ^{0}C temperature per month.

The mean relative humidity was highest (79.60 %) in the month of July, 2023, while the month of January was observed to have the lowest (47.90 %). However, from May to August, 2023, the relative humidity of the study area was observed to be fairly constant.

From the table it was also observed that the month of July, 2023 recorded the highest rainfall (346.70 mm), while the lowest rainfall was observed in December (4.30 mm). However, from September, 2022 to October, 2022 and from May to August, 2023, rainfall was fairly constant.

The month of December, 2022 recorded the highest hours of sunshine (5.30 hours) than the other months. January, 2023 had the second to the highest sunshine hours (5.00 hours), while the months July and August, 2023 were observed to have the lowest (2.60 hours). The sunshine hours were fairly constant from the January to the month of April, 2023 Table 1.

Table 1 Monthly means of daily climatic data of UMUDIKE

Months	Mean temperature (°C)	Mean relative humidity (%)	Rainfall (mm)	Sunshine duration (hours)	Wind speed ($ms^{-1}day^{-1}$)	Soil moisture content (m3m-3)
Sept, 2022	27	78.3	322.3	3	28.71	0.33
Oct, 2022	28.2	74.8	273.3	3.7	23.65	0.33
Nov, 2022	28.6	69.8	54.8	4.5	25.35	0.31
Dec, 2022	28.7	59	4.3	5.3	26.1	0.15
Jan, 2023	27.7	47.9	9.1	5	27.92	0.1
Feb, 2023	26.7	50.1	44.5	4.7	26.84	0.18
Mar, 2023	26.8	61.8	86.6	4.8	30.17	0.27
Apr, 2023	25.6	68.3	192.4	4.6	30.74	0.28
May, 2023	25.8	77.3	248.8	4.2	26.6	0.32
Jun, 2023	26.6	75.5	325.4	2.8	27.9	0.37
Jul, 2023	25	79.6	346.7	2.6	28.36	0.34
Aug, 2023	26.8	74.8	306.7	2.6	35.4	0.31

Source (climate data only): National Oceanic and Atmospheric Administration/National Centres for Environmental Prediction (NOAA/NCEP) under the National Weather Service, United States of America, 2022 - 2023.

The month of August, 2023 recorded the highest wind speed (35.40 ms^{-1} day^{-1}) than the other months. April, 2023 had the second to the highest wind speed (30.74 ms^{-1} day^{-1}), while the month October was observed to have the lowest (23.65 ms^{-1} day^{-1}). The wind speed was fairly constant from the September to December, 2022 and from May to July, 2023.

From the table it was also observed that the month of June, 2023 recorded the highest soil moisture content (0.37 m^3m^{-3}), while the lowest soil moisture content was observed in January, 2022 (0.10 m^3m^{-3}). However, from September, 2022 to October, 2022 and from May to August, 2023, soil moisture content was fairly constant.

Relationship between temperature and soil moisture content

Figure 4.1 shows the relationship between mean monthly temperature and soil moisture content. The results shows that the coefficient of determination (R^2) is 0.1478 which is an indication that the mean temperature is important and has a weak negative influence in the variations of soil moisture using the model (***SMC = -0.0278TEMP + 1.0244***). From the results, the higher the mean monthly temperature, the lower the soil moisture content.

The influence of atmospheric temperature on soil moisture content may be as a result of changing the rate of evapotranspiration and by altering the amount and distribution of precipitation.[18] Higher atmospheric temperature increases the rate of evaporation, which means more water is lost from the soil to the air.[19] This reduces the soil moisture content and makes the soil drier. Conversely, lower atmospheric temperature decreases the rate of evaporation, which means less water is lost from the soil to the air.[20] This increases the soil moisture content and makes the soil wetter. Atmospheric temperature affects transpiration by affecting the photosynthesis rate, which is the process of converting light energy into chemical energy by plants. The higher the temperature, the higher the photosynthesis rate, and the higher the transpiration rate. This means that plants use more water from the soil when the temperature is high (IPCC, 2014) Figure 1.

Higher atmospheric temperature increases the amount of water vapor in the air, which means more water is available for precipitation.[1,21] This increases the soil moisture content and makes the soil wetter. However, lower atmospheric temperature also changes the distribution of precipitation, which means some regions may receive more or less snowfall than usual. This can affect the temporal variability of soil moisture content and create seasonal changes in soil wetness or dryness.[18]

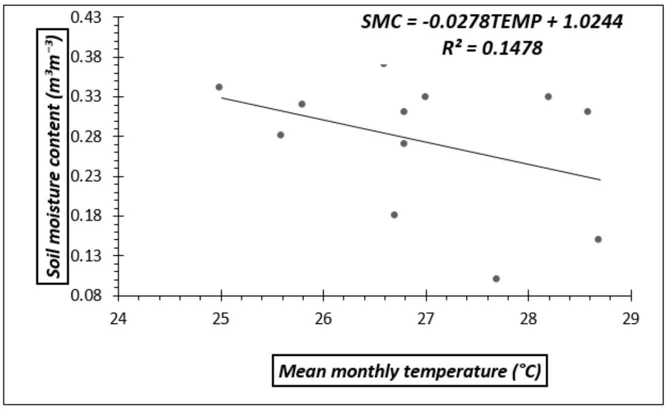

Figure 1 Regression analysis between soil moisture content and temperature.

Relationship between relative humidity and soil moisture content

The regression analysis between mean relative humidity and soil moisture content is presented in Figure 2. The results showed that relative humidity had a strong, positive influence on the variation of soil moisture content. As the relative humidity increased, the soil moisture increased. From the result presented, the model (***SMC = 0.0072RH - 0.215***) showed that relative humidity had about 86.31 % (R^2= 0.8631) control over the variations of soil moisture.

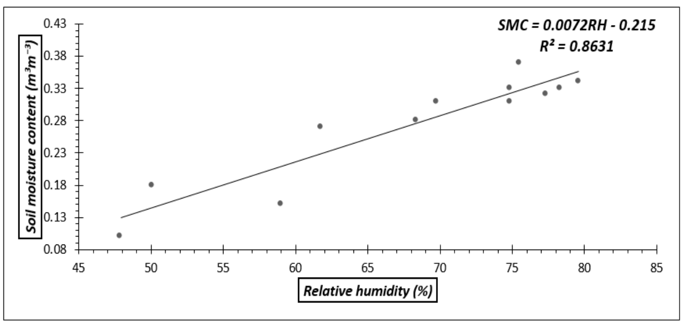

Figure 2 Regression analysis between soil moisture content and relative humidity.

Citation: Onwuka BM, Nwagbara MO, Oguike PC. Evaluation of soil moisture in relation to climate variability across Umudike, South eastern Nigeria. *Int J Hydro.* 2024;8(3):93–98. DOI: 10.15406/ijh.2024.08.00379

The control of relative humidity on soil moisture could be related to water vapor. This is because water vapor can move between the air and the soil through evaporation and condensation processes.[22] When relative humidity is high, it means that the air is close to saturation and cannot hold much more water vapor. This reduces the rate of evaporation from the soil surface, which means that less water is lost from the soil. Conversely, when relative humidity is low, it means that the air is dry and can hold more water vapor. This increases the rate of evaporation from the soil surface, which means that more water is lost from the soil.[23] Therefore, relative humidity tends to decrease soil moisture content when it is low and increase it when it is high.

As the relative humidity increases, the soil moisture content tends to increase as well, because more water vapor condenses on the soil surface and infiltrates into the soil pores.[4,24] When relative humidity is high, the air is saturated with water vapor and the evaporation rate from the soil surface is low. This means that more water stays in the soil and the soil moisture content increases. On the other hand, when relative humidity is low, the air is dry and the evaporation rate from the soil surface is high.[21,7] This means that more water leaves the soil and the soil moisture content decreases.

Relationship between rainfall and soil moisture content

Figure 4.3 presented the regression analysis between rainfall and soil moisture. From the result, the coefficient of determination is 0.6904. This shows that in the model (***SMC = 0.0005RF + 0.1781***) rainfall has about 69.04 % control over the variations of soil moisture content. The results showed that there was a positive control of rainfall over the soil moisture. A higher rainfall amount was observed to increase the moisture content of the soil.

The influence of rainfall on soil moisture could be as a result of the intensity, duration, frequency, and spatial distribution of the rainfall events.[8] Intense and short-duration rainfall events can increase soil moisture content rapidly, especially in coarse-textured soils that have high infiltration rates.[9] Long-duration and low-intensity rainfall events can increase soil moisture content gradually, especially in fine-textured soils that have low infiltration rates.[4,25] Hanks et al.,[10] observed that spatially heterogeneous rainfall events can create patches of high and low soil moisture content, depending on the location and size of the rainfall cells.

Santisopasri et al.[26] observed that rainfall could increase soil moisture by adding water to the soil surface, which infiltrates into the soil pores and fills them up. The rate of infiltration depends on the soil characteristics and the rainfall characteristics. Similarly, high-intensity rainfall can cause surface runoff and erosion, while low-intensity rainfall can infiltrate deeper into the soil profile Figure 3.[8,27]

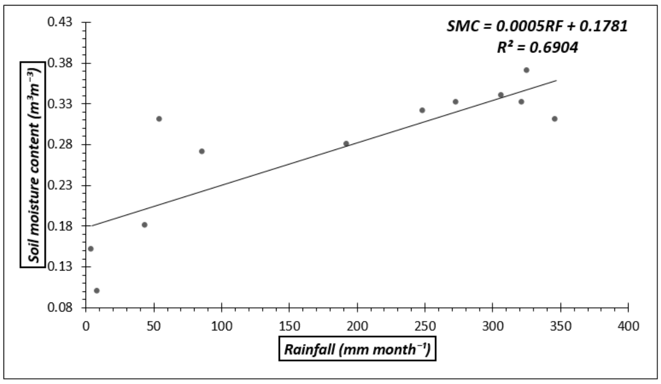

Figure 3 Regression analysis between soil moisture content and rainfall.

Relationship between sunshine duration and soil moisture content

From Figure 4, the relationship between sunlight duration and soil moisture content shows that the coefficient of determination (R^2) is 0.5743 (57.43 %) which is an indication that the sunlight duration is important and has a negative influence on the variations of soi moisture content using the model (***SMC = -0.0645SD + 0.5311***). A higher duration of sunlight was observed to reduce the moisture content of the soil.

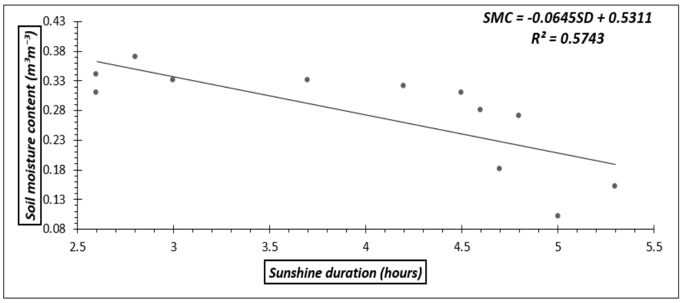

Figure 4 Regression analysis between soil moisture content and sunshine duration.

The control of sunlight duration on soil moisture content could be ascribed to its effect on evaporation and precipitation.[28] The more solar radiation there is, the more energy is available to evaporate water from the soil. Therefore, longer sunlight duration tends to increase evaporation and decrease soil moisture content.[29] Sunlight duration affects evaporation by providing heat and radiation to the surface. Generally, longer sunlight duration increases the rate of evaporation and transpiration, which decreases the soil moisture content (Schubert *et al.,* 2014). Conversely, shorter sunlight duration decreases the rate of evaporation and transpiration, which increases the soil moisture content.

The more cloud cover there is, the less solar radiation reaches the ground and the less evaporation occurs (Hong and Kalnay, 2010). Therefore, shorter sunlight duration tends to decrease evaporation and increase soil moisture content Figure 4.

Relationship between wind speed and soil moisture content

The regression analysis between wind speed and soil moisture content is presented in Figure 5. The results showed that wind speed had a very weak negative influence on the variation of soil moisture content. As the wind speed increased, the soil moisture content had little or no significant effect. From the result presented, the model (***SMC = 0.0028WS + 0.1947***) showed that wind speed had about 1.01 % (R^2= 0.1010) control over the variations of soil moisture content.

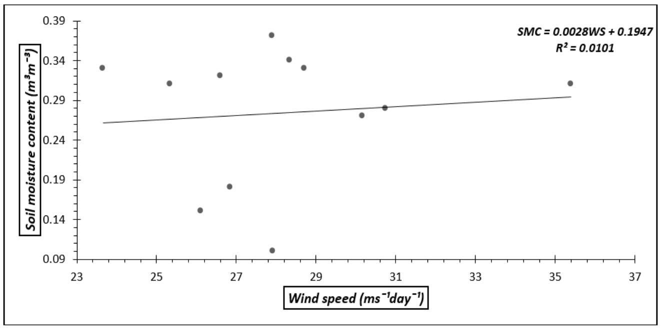

Figure 5 Regression analysis between soil moisture content and windspeed.

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The influence of wind speed on soil moisture content could be attributed to evaporation and advection (Woodward *et al.,* 2011). Wind speed can influence evaporation by affecting the temperature and humidity of the air above the soil surface. Higher wind speeds can increase evaporation by bringing warmer and drier air to the soil surface, which creates a larger gradient of vapor pressure between the soil and the air. This means that more water molecules can escape from the soil to the air, reducing the soil moisture content. Conversely, lower wind speeds can decrease evaporation by bringing cooler and more humid air to the soil surface, which creates a smaller gradient of vapor pressure between the soil and the air. This means that fewer water molecules can escape from the soil to the air, increasing the soil moisture content Figure 5.

Wind speed can influence advection by affecting the direction and distance of air movement. Higher wind speeds can increase advection by transporting more water vapor over longer distances, which can affect the soil moisture content of different regions.[30] For example, if a high wind speed brings moist air from the ocean to a dry land area, it can increase the soil moisture content of that area by depositing water vapor on the soil surface through condensation or precipitation. On the other hand, if a high wind speed brings dry air from a desert to a wet land area, it can decrease the soil moisture content of that area by removing water vapor from the soil surface through evaporation or sublimation. Conversely, lower wind speeds can decrease advection by transporting less water vapor over shorter distances, which can have less impact on the soil moisture content of different regions.

Higher wind speed increases the rate of evaporation and transpiration, which reduces the soil moisture content.[11] This is because the wind removes the water vapor from the air near the soil and plant surfaces, creating a steeper vapor pressure gradient that drives more water loss. Lower wind speed decreases the rate of evaporation and transpiration, which increases the soil moisture content.[23] De Jong and Bootsma[31] observed that wind speed also affects soil moisture content by influencing the transport of water vapor in the atmosphere. Wind can carry water vapor from humid regions to dry regions, or vice versa, altering the local precipitation patterns and soil moisture distribution.[7] Wind speed can also affect soil moisture content indirectly by influencing other factors such as temperature, humidity, solar radiation, cloud cover, and atmospheric pressure, which all have an impact on evaporation and transpiration processes.[5]

Wind speed influences the transport of water vapor and heat in the atmosphere, which affects the precipitation patterns and the energy balance of the soil.[6] It can also cause soil erosion and deposition, which alters the soil structure and texture, and consequently the water holding capacity and infiltration rate of the soil.[30]

Conclusion

The evaluation of soil moisture in relation to climate variability was carried out in Umudike, Abia state. The objective of the study was to evaluate the relationship between soil moisture and climatic parameters in Umudike. The relationship between the rate of soil moisture and has been established in Umudike area. The atmospheric temperature and sunlight duration had an inverse proportionality to soil moisture. This shows that an increase in atmospheric temperature and sunlight duration will result to decrease in soil moisture. The relationship between individual climatic parameters and soil moisture shows that soil moisture has strong, direct, proportional relationship to rainfall and relative humidity but weakly related to wind speed. Further study can be done to predict the moisture requirements for some selected crops.

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Conflicts of interest

The author declares there is no conflict of interest.

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