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Effect of Climate Change on Soil Moisture and Soil Organic Matter in the Past and Future Years of the Soil Properties in Otta Farm

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Abstract. Increased temperature affects microbial activity both directly and indirectly through its impact on soil moisture and the quantity of organic matter. When soil temperature changes as a result increased atmospheric temperature, the composition of the microbial community and the moisture content of the soil is affected. Increase in temperature decreases organic matter through combustion. This is an important factor to predicting to predicting the effect of climate change on soil properties. In a government farmland (Otta, Agbowa-Ikosi. Lagos state) we determined the effect of climate change on soil moisture and organic matter. The relationship among temperature, precipitation, soil moisture and organic matter was investigated. Two hundred soil samples were randomly collected on the farmland and were taken to the laboratory for the analysis to determine the soil moisture and organic matter content. Precipitation and temperature data were collected from 1996-2016. A correlation analysis was carried out between soil and climatic variables. Findings indicated a non-significant correlation between the soil properties and climatic variables but a negative correlation coefficient between soil organic matter and precipitation (-0.511), soil moisture and temperature (-0.384), a positive correlation coefficient between soil organic matter and temperature (0.377), soil moisture and precipitation (0.517) which reveals the direction and strength of the variables. The study concludes that temperature and precipitation affected soil moisture and organic matter from 1996-2016. However, recommendation includes the application of organic materials on soil to increase organic matter content and the practise of mulching will also conserve soil moisture.

Keywords: Climate change, organic matter, soil moisture, temperature and precipitation.

1. Introduction

In Nigeria, climate change has altered the weather pattern such as increasing cases of dry spells, drought and unpredictability of rainfall. Soils are important enabling resource and crucial to the production of a wide range of goods and services fundamental to ecosystems and the well-being of humans (Abdul et al. 2023). Recent climate change has had widespread impacts on natural systems including shifts in the ranges (distributions) of land, freshwater, and marine organisms. Effects of these biogeographical shifts transcend single-species to impact on ecosystem goods and services resulting in significant social and economic costs to human communities (Aydinalp, 2008). Climate change can alter the spatial and temporal availability of soil and water resources. These changes will result in increased floods and drought, which will have significant impacts on soil and water resource availability. Thomson (2022) explained that increase in temperature causes organic matter to decompose faster due to the enhancement of the mobility of soluble substrates occurring in the soil thereby activating the activities of microbes. Usually, organic matter decomposes faster with risen temperature. In many ecosystems, the decomposition of soil organic matter is greatly determined by the changes in soil moisture content due to climate change. Mandal & Sathyaseelan (2012) explained that the unsaturated zone in the soil may be influenced by sufficient aerobic processes which increase the decomposition rate of organic matter. Also, rise in atmospheric temperature as a result of climate change increases the soil temperature which increases the decomposition and loss of organic matter (Karmakar, 2016)

2. Literature Review

The Intergovernmental Panel on Climate Change (IPCC) stated that climate change is emerging as one of the cardinal challenges of the 21st century

(Akamigbo and Nnaji, 2011). There is a widespread consensus among the scientific community that the earth is warming and the consequences of this are likely to be severe and this is a challenge to sustainable development (Rebecca *et. al*, 2019). Agriculture, and consequently food security, is already being affected by climate change through flooding and drought (Naschen, et al. 2019). This is because excessive precipitation caused by climate change washes away essential nutrients needed by plant and extreme temperature caused by climate change results into high decomposition of organic matter and soil water deficit which reduce the division of plant cells and cell growth; this ultimately leads into low crop yield. However, Patil and Laminganbi (2018) explained that Climate change can affect soil functions directly by temperature, precipitation, and moisture regime changes, and indirectly by adaptations such as irrigation, crop rotation changes, and tillage practices. Climate change causes rise in atmospheric carbon dioxide levels, elevated temperature, altered precipitation and atmospheric nitrogen deposition on physical, chemical and biological functions of soil (Hamidov et al. 2018).

In addition, changes in precipitation patterns caused by climate change could consequently modify the magnitude of the soil carbon (C) sink, as precipitation has been commonly considered as a modifier of soil C cycling by changing soil moisture and underground hydrological processes (Chen et al.2015). Some of the identified impacts of climate change on the soil are reduction in soil biodiversity, soil erosion, excessive soil wetness, high soil temperature, depletion of soil organic pool and a general decrease in the overall quality of the soil for agricultural (Gelybo et al, 2018).

3. Materials and Methods

3.1 Location of the Study Area

The study area, Otta farm is located in Agowa-Ikosi in Lagos State. The area experiences a tropical savanna climate with dry winters, based on climatological records spanning from 1991 to 2021. June temperatures gradually decrease with daily highs averaging around 29°C, rarely dropping below 27°C or exceeding 32°C. Thunderstorms are common during this month, with relative humidity ranging from 68% to 98%, peaking towards the end of June. Vegetation comprises swamp forests along the coastal belt, consisting of mangroves and coastal vegetation, and dry lowland rainforests with economically valuable trees. Soil types include juvenile soils, fluviomarine alluvium, red ferritic soils, and coastal plain sands, with elevation varying from 1 m to 8 m above sea level, underlain by soft clays/silts and loose sands.

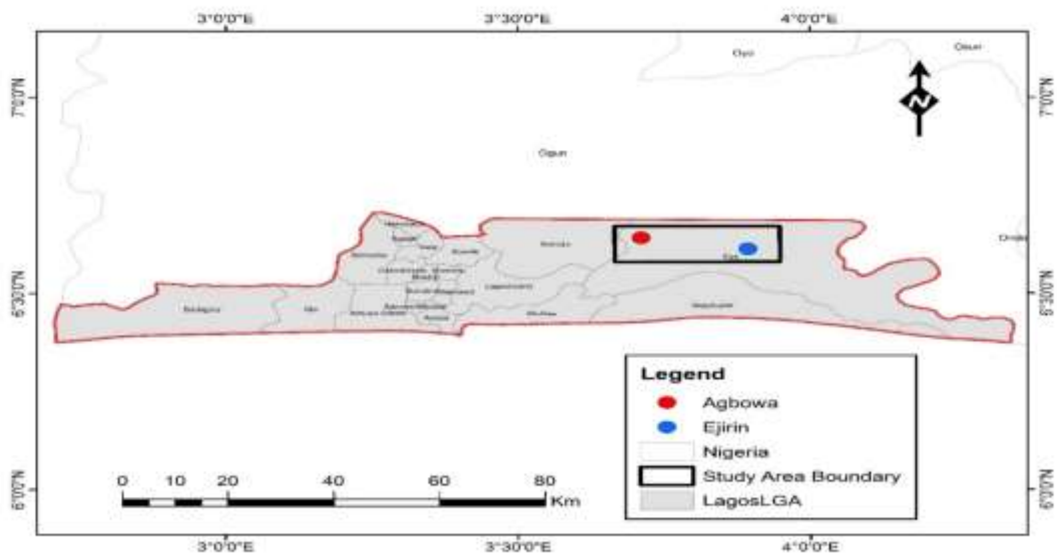

Figure 1: Map of Lagos State Showing the Location of the Study Area

3.2 Data Types and Source

In this study, two types of data were use; primary data, and secondary data. Primary data were obtained from field observation and soil sampling in the field, and Landsat 8 OLI/TIRS image data obtained from USGS website. The Secondary data used were Landsat 8 Imagery which was gotten from earth explorer (30meters) and Monthly

Temperature and Precipitation data of 20 years were gotten from Nigeria Meteorological Agency (NIMET). A person correlation analysis was carried out to determine the correlation between the soil properties Soil Organic Matter (SOM) and Soil Moisture (SM) and the climatic variables (Rainfall and Temperature) from the year 1996-2016.

3.3 Soil Sampling Technique

Twenty sites within the farmland were randomly selected within the study area after being divided into grids of 50cm by 50cm. Using the soil auger, 200 soil samples at 15cm depth with their corresponding geographical coordinates were randomly selected within the grids and taken to the laboratory for analysis to determine the soil moisture and organic matter content.

3.4 Methodology

Below is the methodology of SMI and soil organic matter analysis based on the Landsat 8 images which were selected from climatology of precipitation and Temperature. The Landsat 8 images were selected in February, April and June.

3.4.1 Normalised Difference Soil Index (NDSI)

Normalized difference soil index (NDSI) was used for the combination of bands 7 and 2 of Landsat Thematic Mapper Image. This study used the normalised difference soil index (NDSI) algorithm to see the soil organic matter content using Landsat 8 OLI (Operational Land Imager) as a reference for the determination of soil sampling. The combination of bands in this study used a combination of bands 5 and 4 on Landsat 8 OLI.

3.4.2 Future Forecasting of Soil Organic Matter

a. Linear Regression: Multiple linear regression aimed to see the correlation/relationship between the dependent variable of soil organic matter (%) with the free variable which is the pixel value of the image of the normalized difference soil index (NDSI) result. The results of the linear regression statistical test were used to determine the distribution of soil organic matter content.

$SMI=\beta 0+\beta 1X1+\beta 2X2+\ldots+\beta nXn+\varepsilon$

where $X1,X2,\ldots,Xn$ are predictor variables (precipitation, temperature, land cover), $\beta 0,\beta 1,\ldots,\beta n$ are coefficients, and ε is the error term.

Also, the atmospheric temperature of the study area was obtained from the thermal bands of the same Landsat image.

b. Calculation of Landsat Temperature (LT)

Calculation of Atmospheric Temperature During 1G-product rendering, image pixels were converted to units of absolute radiance using 32 bit floating-point calculations. Pixel values were then scaled to byte values prior to media output. The following equation was used to convert DN(Digital Number)'s in a 1 G product back to radiance unit for TM(Thematic Mapper) and ETM(Enhanced Thematic Mapper)+:

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN} \right) * \left(QCAL - QCALMIN \right) + LMIN_\lambda$$

Where, Lλ is spectral radiance at the sensor's aperture in watts/(meter squared * ster * µm), QCAL is the quantized calibrated pixel value in DN, LMINλ is the spectral radiance that is scaled to QCALMIN in watts/(meter squared * ster * µm), LMAXλ is the spectral radiance that is scaled to QCALMAX in watts/(meter squared * ster * µm), QCALMIN is the minimum quantized calibrated pixel value (corresponding to LMINλ) in DN, and QCALMAX is the maximum quantized calibrated pixel value (corresponding to LMAXλ) in DN. The following equation is used to convert DN's in a 1 G product back to radiance unit for TIRS:

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

Here, ML is radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata), Qcal is L1 pixel value in DN, and AL is radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata). ETM+ Band 6 (thermal) and TIRS (Thermal Infrared Sensor) Band 10 and 11 imagery were converted from spectral radiance to a more physically useful variable. This was the effective at satellite temperatures of the viewed Earth-atmosphere system under an assumption of unity emissivity and using pre-launch calibration constants. The conversion formula is:

$$T = \frac{K2}{\ln\left(\frac{K1}{L_\lambda} + 1\right)}$$

Where, T is brightness temperature (K), K2 is calibration constant 2, and K1 is calibration constant 1.

c. Calculation of Normalized Difference Vegetation Index (NDVI)

NDVI was calculated from the visible and near-infrared light reflected by vegetation. NDVI can be calculated by the following equation:

$$NDVI = \frac{NIR - VISR}{NIR + VISR}$$

Where, Near Infrared (NIR) is spectral reflectance measurements acquired in the near infra-red regions and VISR is spectral reflectance measurements acquired in the visible red regions. A value between -1 and + 1 was generated from the result of this formula. If it had low reflectance (or low values) in the red channel and high reflectance in the NIR channel, this produced a high NDVI value and vice versa.

d. Calculation of Normalized Difference Water Index (NDWI)

The formula stands for NDWI is given below

$$NDWI = \frac{VISG - NIR}{VISG + NIR}$$

Where, NIR is spectral reflectance measurements acquired in the near infra-red regions and VISG is spectral reflectance measurements acquired in the visible red regions. This formula generated a value between -1 and +1. If it had low reflectance (or low values) in the red channel and high reflectance in the NIR channel, this yielded a high NDWI value and vice versa.

e. Conversion of Atmospheric Temperature to Land surface Temperature (LST)

After calculating NDVI for a specific year, it yielded either a positive or a negative NDVI value. Then using the NDVI value, the proportion of vegetation is calculated from the following equation:

$$P_v = \left(\frac{NDVI - NDVI_{MIN}}{NDVI_{MAX} - NDVI_{MIN}}\right)^2$$

Where, P_v refers to proportion of vegetation.

Then using the value of Pv Land Surface Emissivity (LSE) was also calculated. The knowledge of LSE was necessary to apply the methods of retrieving LST (Land Surface Temperature) from a Landsat image. The final expression for calculating emissivity based on this method is:

$$e = 0.004P_v + 0.986$$

Where e denotes LSE. Finally, LST is derived using the following equation:

$$LST = \frac{T}{1 + \frac{wT}{p} \times \ln(e)} - 273.15$$

Where, W is emitted radiance wavelength (μm), p=h/s=1.438*10-2 mK, h is the constant of Planck’s (6.626*10-34 Js), s is constant of Boltzmann (1.38*10-23 J/K), c is light Velocity (2.998*10-8 m/s).

4. Results and Analysis

It was observed that there was no significant association between climatic variables (Temperature and Rainfall) and the soil properties (Soil Organic Matter and Soil Moisture). This result has implications.

4.1 The evaluation of Soil Organic matter in past years (1996, 2006 and 2016).

It can be observed in figure 2 that in year 1996, SOM varied between 0.03gm^2 -0.05 gm^2 where most of the sites fell within 0.04 gm^2 -0.05 gm^2 and the control point fell within the range of 0.03 gm^2 – 0.04 gm^2. In year 2006, SOM varied between the range of 0.10-0.22gm^2 and there was an increase of SOM in year 2006 as SOM increased from 0.03 gm^2- 0.04 gm^2 in year 1996 to 0.10 gm^2-0.22 gm^2 in year 2006 while in year 2016 SOM ranged between 0.07-0.11 gm^2.

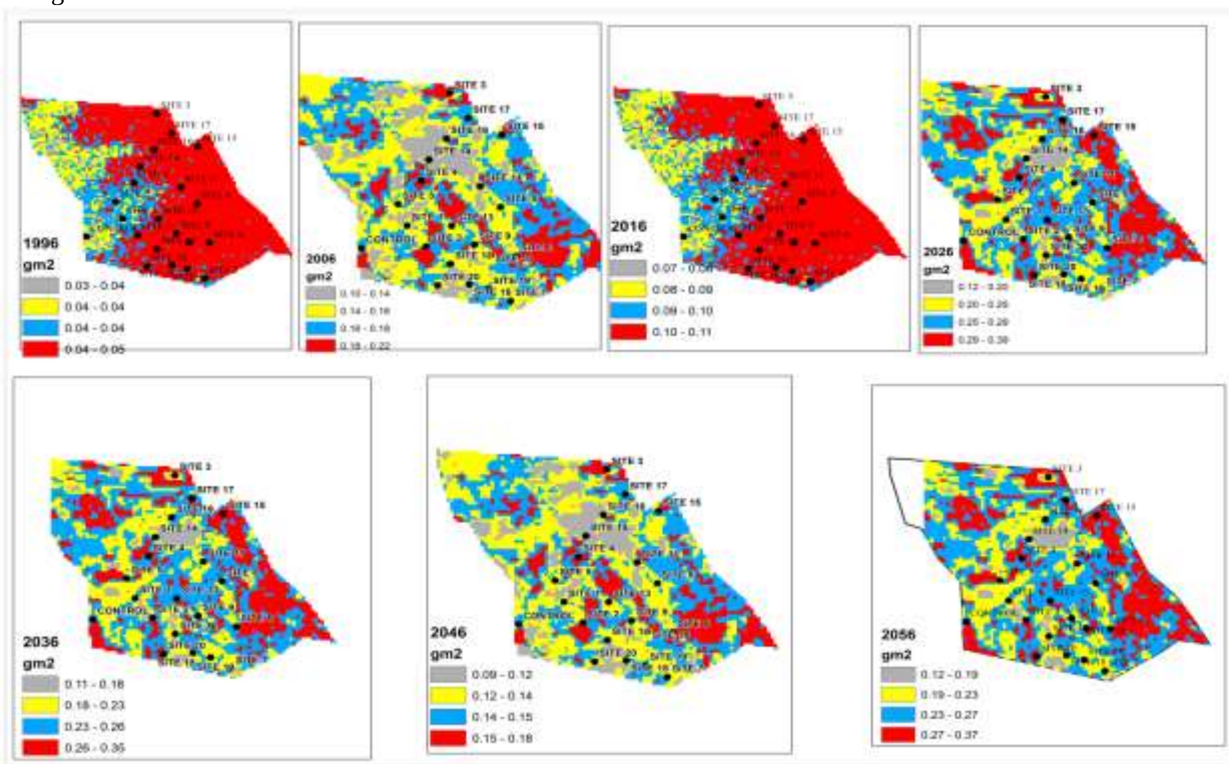

Figure 2: *Map Showing the Soil Organic Matter Content in the Study Area.*

4.2 The evaluation of Rainfall on Soil Organic matter in past years.

It can be observed in table 1 that there was no significant association between SOM and Precipitation from the year 1996 – 2016 but there was a moderately negative correlation co-efficient between the two variables (-0.511) such that as precipitation increased OM decreased. This does not align with many explanations in literature because increased precipitation enhances the rapid decomposition of organic materials to form organic matter (Jiang et al. 2021). Soil organic matter could reduce with increased Rainfall because of the changes in climatic condition that took place during the years, the hydrology of the terrain, changes in land use and vegetation over the years.

Table 1: Correlations between Soil Organic Matter and Rainfall

		Soil Organic Matter	Precipitation
Soil Organic Matter	Pearson Correlation	1	-.511
	Sig. (2-tailed)		.659
	N	3	3
Precipitation	Pearson Correlation	-.511	1
	Sig. (2-tailed)	.659	
	N	3	3

4.3 The evaluation of Temperature on Soil Organic matter in past years.

According to table 2, there was no significant association between SOM and Temperature from the year 1996-2016 but there was a low positive correlation coefficient between the two variables (0.377). This means that as Temperature increases, SOM also increases. This does not align with many explanations in literature. This is because regions of higher temperature have lesser OM due to the fact that OM decays more rapidly at higher temperature, thus regions with low temperature have more OM content. Thomson (2022) confirmed that increase in temperature causes OM to decompose faster due to the enhancement of the mobility of soluble substrates occurring in the soil thereby activating the activities of microbes. This affirms the Kinetic Theory which explains that the application of heat to a substance makes the particles of the substance to be in vigorous motion because increase in temperature increased the rate of decomposition of organic matter in soil.

However, the increase of Organic Matter despite the increased Temperature that occurred over the years could be caused by the addition of Organic materials such as solid or liquid manures, residues of crops and the deliberate reduction of drainage and the cultivation of soil to reduce the decomposition of organic matter by farmers within the study area.

Table 2: Correlations between Soil Organic Matter and Temperature

		Soil organic matter	Temperature
Soil Organic Matter	Pearson Correlation	1	0.377
	Sig. (2-tailed)		0.754
	N	3	3
Temperature	Pearson Correlation	0.377	1
	Sig. (2-tailed)	0.754	
	N	3	3

4.4 The Evaluation of Soil Moisture in past years (1996, 2006 and 2016).

It can be seen in figure 3 that in year 1996, the SMI ranged between 34.85%-60.19% where most of the sites within the study area fell between 49.65%-60.19%. In the year 2006, the SMI ranges between 13.94%-24.07% where most of the sites are within the range of 19.86%-24.07%. Also, there was a decline in the trend of SMI from 1996-2006 and in year 2016, the SMI ranged between 69.50%-99.30%.

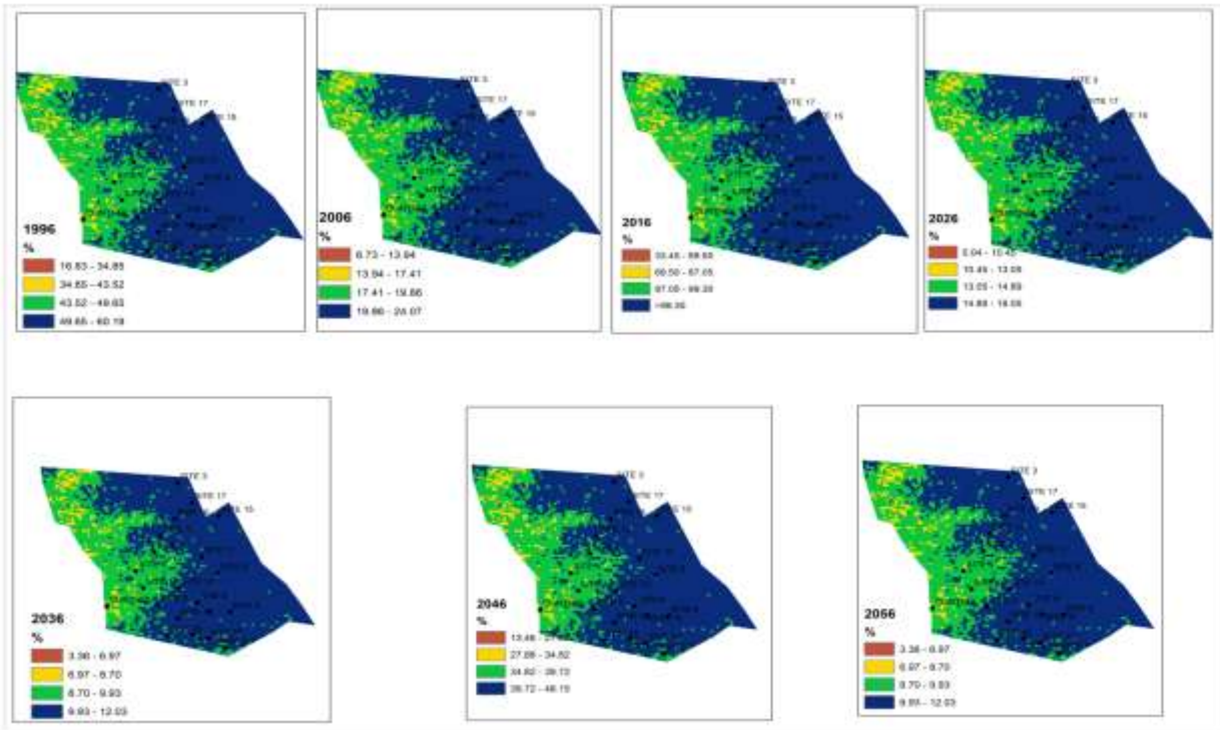

Figure 3: *Map Showing the Soil Moisture in the Study Area.*

4.5 The Evaluation of Rainfall on Soil Moisture in past years.

It was observed in the table 3 that there is no significant association between Soil Moisture and Precipitation from 1996-2016 but there is a moderately positive correlation coefficient between the two variables (0.517). This means that as Precipitation increase, Soil Moisture also increases. This aligns with explanations in literatures. In the work of Dubinin et al. (2020), using LANDSAT 8 and VENUS data to study the effect of Geodiversity on soil moisture dynamics in a semi and shrub land, it was observed that severe deficit of soil moisture is caused by decrease in the rate of rainfall and increase in the temperature due to global warming. Also, using sentinel-2 satellite imagery and SNAP software, Roohi et al. (2021) opined that soil moisture reduced over the years as a result of lack of optimal pattern of cultivation, which also led to land subsidence and increased salinity.

Qin et al. (2023) emphasised that since the 21st century; soil moisture had decreased significantly and would continue to decrease in future due to global warming as postulated in the theory of Anthropogenic Global Warming.

Table 3: Correlations between Soil Moisture and Rainfall

		Soil moisture	Precipitation
Soil Moisture	Pearson Correlation	1	0.517
	Sig. (2-tailed)		0.654
	N	3	3
Precipitation	Pearson Correlation	0.517	1
	Sig. (2-tailed)	0.654	
	N	3	3

4.6 The evaluation of Temperature on Soil Moisture in past years.

It can be seen in table 4 that there was no significant association between Soil Moisture and Temperature from the year 1996-2016 but there was a low negative correlation coefficient (-0.384) between Soil Moisture and Temperature. This implies that as temperature increases, soil moisture reduces. Temperature affects the rate of nitrification and soil moisture content. Furthermore, Onwuka and Mang (2018) explained that factors of the environment influences the temperature of the soil either by determining the amount of heat supplied to the soil or the amount of heat evaporated from the surface of the soil down the profile. Also, increased temperature cause moisture in soil to evaporate rapidly which consequently leads to decrease in soil moisture.

Table 4: Correlations between Soil Moisture and Temperature

		Soil moisture	Temperature
Soil moisture	Pearson Correlation	1	-0.384
	Sig. (2-tailed)		0.749
	N	3	3
Temperature	Pearson Correlation	-0.384	1
	Sig. (2-tailed)	0.749	
	N	3	3

4.7 Prediction of Soil Organic Matter (2026, 2036, 2046 and 2056)

A projected content of Soil Organic Matter in year 2026 can be seen in figure 2 where the SOM varied between $0.12gm^2 – 0.39gm^2$. In year 2036 as seen in figure 4.56, SOM within the study area was predicted to be between 0.11 gm^2 – 0.35 gm^2. This shows a decline in SOM from the year 2026 - 2036. A reason for this could be due to the changes in climate conditions, the type of soil texture, hydrology of the terrain changes in the landuse and vegetation Glanz (1995) stated that tillage practices reduce SOM than other practices. This is because tilling the soil aerates the soil, knowing that the decomposition of OM is an aerobic process, thus, the oxygen enhances the action of soil microbes that eat up organic matter-reducing it.

In year 2046, the Soil Organic Matter was projected to be 0.09 gm^2 – 0.18 gm^2 as seen in figure 2. This also shows a decline between year 2036-2046 which fell between the range of 0.11 gm^2 – 0.35 gm^2 and 0.09 gm^2 – 0.18 gm^2 respectively. However, the projected content of SOM in the year 2056 ranges between 0.12 gm^2 – 0.37 gm^2 which depicts an increase in SOM from year 2046 – 2056 which ranges between 0.09 gm^2- 0.18 gm^2 and 0.12 gm^2 – 0.37 gm^2 respectively. A reason for the increase of SOM in the prediction could be because Increase in precipitation generally results in an increase in the level of OM, this is because elevated level of moisture in the soil results into a greater production of biomass from the residue of materials from plants and animals (Primavesi, 1984). Rocci et al. (2023) sampled soils from a 30-year precipitation augmentation experiment in annually burned mesic grassland, it was observed that there were no changes in bulk carbon or Nitrogen with increased precipitation but organic matter in soil were modified.

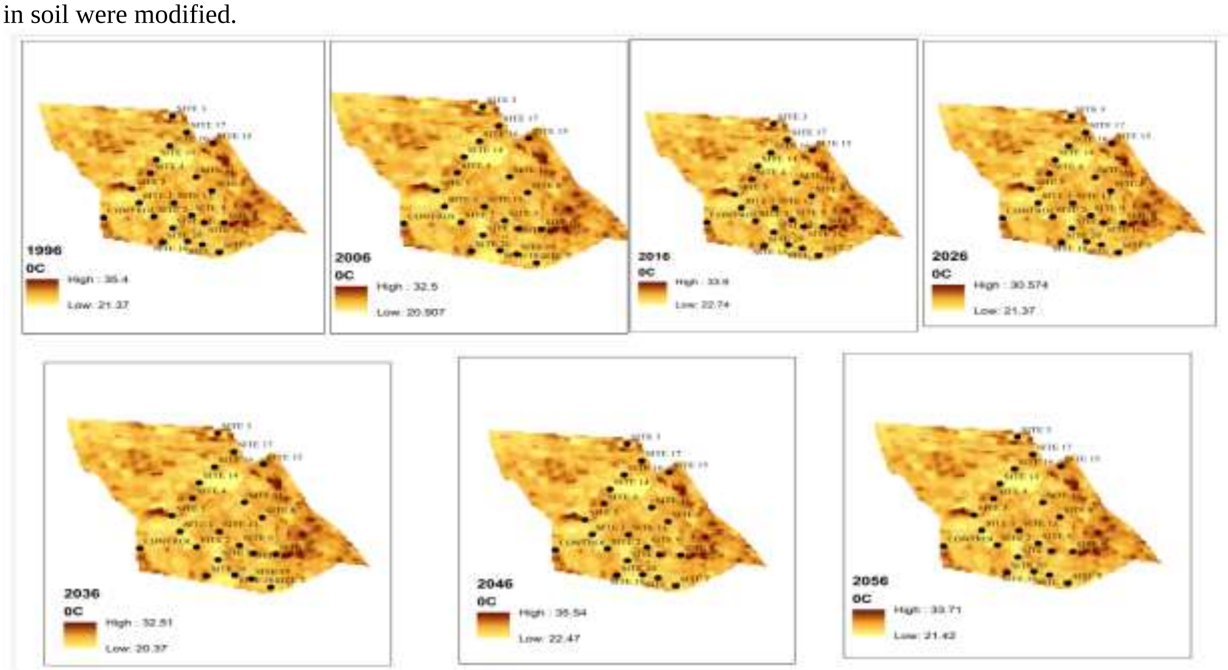

Figure 4: *Map Showing the Soil Temperature of the Study Area*

4.8 Prediction of Atmospheric Temperature and how Soil Organic Matter would be affected in year (2026, 2036, 2046 and 2056)

It was predicted that the temperature increased from year 2026 to year 2056 in figure 4. This was because in 2026, the surface temperature ranges between 21.37^0C -30.57^0C. In year 2036, the temperature ranges between 20.37^0C- 32.51^0C, in year 2046, the temperature was predicted to be between 22.47^0C - 35.54^0C and lastly, in year 2056, the temperature was predicted to be between 21.42^0C-33.71^0C.

Regions with high temperature cause high biomass productivity and the decomposition of microbial organic matter than regions with lower temperature. Lehnert (2014) explained that many microbial processes within the soil which are responsible for the decomposition of Organic Matter are affected by temperature which also alters the rate of mineralisation of various organic compounds. Peera (2020) emphasised that optimum temperature for the decomposition of mcrobes may be between 35^0C - 40^0C. Onwuka and Mang (2018) opined that increased soil temperature affects the rate of decomposition of OM, Soil Moisture content and the availability of water to plants.

4.9 Prediction of Soil Moisture (2026, 2036, 2046 and 2056)

A potential insight into 2026 can be seen in figure 3. The prediction displayed the changes to occur in year 2026. The prediction indicated that within the study area, the SMI would be between the ranges of 10.45% - 18.05%. In 2036 SMI would be between 6.97% - 12.03%. This depicts that there would be a decline of the SMI from year 2026-2036 but would increase from year 2036 to 2046 which ranges between 27.88% - 48.15% as seen in figure 3. The reason for this could be attributed to the fact that soil moisture increases by intense increase of hydrological extreme caused by climate change (Czigany et al. 2023). In addition, high rainfall increases the soil moisture and increases the pore pressure which consequently reduces the strength of the soil (Tajudin et al. 2021).

Furthermore, the prediction displays the SMI within the study area of the year 2056 to be between 6.97%-12.03% as seen in figure 3. This explains a decline of SMI from year 2046 to year 2056. This aligns with the work of Roohi et al. (2021). They used Sentinel-2 satellite and SNAP software to explain that soil moisture reduced over the years as a result of lack of optimal pattern of cultivation, which also lack optimal pattern of cultivation which also led to land subsidence and increased salinity.

4.10 Prediction of Atmospheric Temperature and the effect on the Soil moisture index in year (2026, 2036, 2046 and 2056).

In year 2026, the temperature was seen to be between 21.37^0C – 30.57^0C in figure 4. In year 2036, the temperature increased to 20.37^0C – 32.51^0C. In year 2046, an increase in temperature was predicted to take place. Finally, in year 2056, there was also a predicted increase of temperature of the study area to be between 21.42^0C – 33.71^0C. The reason for the predicted increase in temperature could be attributed to the reason that climatic condition influences soil temperature. Temperature is affected by the factors that affect the transfer of heat through the atmosphere from the sun. This aligns with the theory of Solar Variability which explains that the sun accounts for the warming of the earth's temperature and the earth's temperature will increase and dominate the climate in the 21^{st} century.

The transfer of heat into the soil is dependent on the angle on incident radiation, direction of slope, steepness, altitude, latitude, time of the day and amount of precipitation (Yolcubal & Wilson, 2004). Furthermore, increase of extreme weather events could be caused by climate change which would result into series of intense dryness of the soil and intense increase of wetness of the soil (Dunne, 2019).

Khamidov et al. (2023) stated that soil moisture evaporates rapidly from the soil as the temperature increases which often led to the decrease of ground water. The soil moisture will also be altered by increase in temperature which would lead to altering the composition of microbiological community in the soil through various mechanisms like the changes in metabolic activities (Dowdeswell-Downey et al. 2023).

5. Conclusion and Recommendations

Soil to a large extent which is dependent on the climate as a whole and on temperature and precipitation in particular, also the negative effect of climate change most often alters the chemical properties of the soil. Furthermore, the fertility of the soil is determined by the content of soil organic matter and soil moisture. This study recommends that cropland should be moved to drought-free areas, planting and harvesting time should be adjusted and mulching should be practised in order to prevent run-off, moderate the soil temperature and evaporation to retain soil moisture and organic matter.

References

Abdu, A., Laekemariam, F., Gidago, G. & Getaneh, L. (2023). Explaining the Soil quality using Different Assessment Techniques. 2023.15. Available online at https://doi.org/10.1155/2023/6699154

Akamigbo, F. O. R. and Nnaji, G. U. (2011). Climate Change and Nigerian Soils: Vulnerability, Impact and Adaptation. Agro-Science *Journal of Tropical Agriculture, Food, Environment and Extension*. Department of Soil Science, University of Nigeria, Nsukka, Nigeria, 10(1), pp. 80-90.

Aydinalp, C. (2008). The effects of global climate change on agriculture. *American-Eurasian Journal of Agriculture and Environmental Science*, 3 (5), 672-676.

Chen, X.,Zhang, D., Liang, G., Qiu, Q., Liu, J., Zhou, G., Liu, S.,Chu, G., & Yan, J. (2015). Effects of precipitation on soil organic carbon fractions in three subtropical forests in Southern China. *Journal of Plant Ecology. School of Geographical Sciences*, 1-10.

Czigány, S., Sarkadi, N., Lóczy, D., Csépl, O, A,; Balogh, R., Fábián, S.Á..,Cigli, C. R., Ferk, M., Pirisi, G., & Imre, M., (2023). Impact of agricultural land use types on soil moisture retention of loamy soils, *Journal of Sustainability*, 15, 4925. https://doi.org/10.3390/su15064925

Dowdeswell-Downey, E., Grabowski, R.C. & Rickson, R.J. Do temperature and moisture conditions impact soil microbiology and aggregate stability?. *Journal of Soils Sediments 23*, 3706–3719 (2023). https://doi.org/10.1007/s11368-023-03628-2

Dubinin, V., Svoray, T., Stavi, I., & Yizhaq, H. (2020). Using LANDSAT 8 and VENµS Data to Study the Effect of Geodiversity on Soil Moisture Dynamics in a Semiarid Shrubland, *Journal of Remote Sensing*, *12*(20), 3377; https://doi.org/10.3390/rs12203377

Dunne, D. (2019). Climate's change impact on soil moisture could push land past "tipping point". Available online at https://www.carbonbrief.org/climate-changes-impact-on-soil-moisture-could-push-land-past-tipping-point/

Gelybo, G., Toth, E., Farkas, C.,Horel, A., Kasa, I.,& Bakacsi, Z. (2018). potential impacts of climate change on soil properties. *Journal of Agrochemistry and Soil Science*, 1, 121-141.

Glanz. (1995). Chapter 4. Practices that influence the amount of organic matter. Available at https://www.fao.org/3/a0100e/a0100e07.htm

Hamidov, A., Helming, K., Bellocchi, G., Bojar, W., Dalgaard, T., Bahadur, B., Hoffmann, C., Holman, I. & Holzkämperm, A. (2018). Impacts of climate change adaptation options on soil functions: A review of European case-studies, 29(8).

Jiang, Z., Bian, H., Xu, L., M., & He, N. (2021). Effects of pulse precipitation on soil organic matter mineralization in forests: spatial variation and controlling factors, *Journal of Plant Ecology*, 14(5), 970–980.

Karmakar (2016). Potential effects of climate change on soil properties. A review, 4(2). pp 51-73

Khamidov, M., Ishchanov, J., Hamidov, A., Shermatov, E. & Gafurov, Z. (2023). Impact of soil surface temperature on changes in the groundwater level, 15(21). 3865; https://doi.org/10.3390/w15213865

Lehnert, M. (2014). Factors affecting soil temperature as limits of spatial interpretation and simulation of soil temperature, 45(1). 5-21.

Mandal, A. & Sathyaseelan, N. (2012). Impact of climate change on soil biodiversity- A review, 33(4)283-292.

Mondal (2021). Impact of climate change on soil fertility. DOI:10.10071978-3-030-7683-8-28

Naschen, K.; Diekkruger, B.; Leemhuis, C.; Seregina, L. S. and Van der Linden, R. (2019). Impact of Climate Change on Water Resources in the Kilombero Catchment in Tanzania. Department of Geography, University of Bonn, Germany, 11, p. 859.

Onwuka, B. & Mang, B. (2018) Effects of soil temperature on some soil properties and plant growth, 8(1).34-37. DOI: 10.15406/apar.2018.08.00288

Onwuka, B. & Mang, B. (2018) Effects of soil temperature on some soil properties and plant growth, 8(1).34-37. DOI: 10.15406/apar.2018.08.00288

Patil, A., & Laminganbi, M. (2018). Impact of climate change on soil health: A Review. *International Journal of Chemical Studies*, 6(3), 2399-2404.

Peera, P. G. (2020). Fundamentals of Soil Science. Available online at :https://courseware.cutm.ac.in/wp-content/uploads/2020/05/S14.pdf

Primavesi, 1984. Natural factors influencing the amount of organic matter. Available online at https://www.fao.org/3/a0100e/a0100e06.htm

Mondal (2021). Impact of climate change on soil fertility. DOI:10.10071978-3-030-7683-8-28

Qin, T., Feng, J., Zhang, X., Li, C., Fan, J., Zhang, C., Dong, B., Wang, H. & Yan, D. (2023). Continued decline of global soil moisture content, with obvious soil stratification and regional difference. *Journal of Science of The Total Environment,* 864.

Rebecca, M. H., Sophus, A. R., Polina, R., and Amram, M. (2019). Climate Change in 2018: Implications for Business. Harvard Business School Publications.

Roohi, M., Faeli, M., Irani, M., & Shamsaei (2021). Calculation of land subsidence and changes in soil moisture and salinity using remote sensing techniques. *Journal of Environmental Earth Sciences,* 80. 423. https://doi.org/10.1007/s12665-021-09723-2

Tajudin, N., Ya'acob, N., Ali, D. M., & Adnan, N. A. (2021). Soil moisture index estimation from Landsat 8 images for prediction and monitoring landslide occurrences in Ulu Kelang, Selangor, Malaysia. *International Journal of Electrical and Computer Engineering*, 11(3). 2101-2108. DOI: 10.11591/ijece.v11i3.pp2101-2108

Thomson, L. (2022). Temperature effects on various soil characteristics and plant growth. *Journal of Environmental Chemistry and Toxicology,* 6(2).

Thomson, L. (2022). Temperature effects on various soil characteristics and plant growth. *Journal of Environmental Chemistry and Toxicology,* 6(2).

Yolcubal, I. & Wilson, L.G. (2004). Environmental physical properties and processes in environmental monitoring and characterization. Available online at: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/soil-temperature