Journal of Environmental Impact and Management Policy
ISSN: 2799-113X
Vol : 03 , No. 04 , June-July 2023
http://journal.hmjournals.com/index.php/JEIMP
DOI: https://doi.org/10.55529/jeimp.34.31.43

Climate Resilience and Ecological Dynamics of the Mpameso Forest Reserve in Ghana: Insights from Land Surface Temperature Analysis

Jeff Dacosta Osei[1*], Desmond Karikari Osei[2], Kwame Obeng[3], Richmond Awotwe[4], Deborah Nketsiah[5]

[1]Department of Geospatial Sciences, University of Energy and Natural Resources, Sunyani, Ghana.*
[2,3,4]Department of Geomatic Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
[5]Department of Atmospheric and Climate Sciences, University of Energy and Natural Resources, Sunyani, Ghana.

Email: [2]oseidesmond285@gmail.com, [3]kwameobeng110215@gmail.com, [4]richiesup@gmail.com, [5]nketsiahdeborah0@gmail.com
Corresponding Email: [1]jeff.osei@uenr.edu.gh*

Received: 27 March 2023 **Accepted:** 14 June 2023 **Published:** 30 July 2023

Abstract: Climate change, characterized by shifts in weather parameters and escalating climate-related risks, has emerged as a global environmental concern. Among these concerns, chronic heat waves have garnered attention due to their far-reaching implications. This study delves into the profound impact of chronic heat waves on the Mpameso forest reserve in Ghana, an ecosystem of vital importance. Chronic heat waves have induced notable changes in the local climate, marked by increased temperatures, elevated evapotranspiration rates, and alterations in rainfall patterns over the past three decades. Ghana, like many regions worldwide, has experienced shifts in seasons and a rising global mean surface temperature, contributing to the intensification of global warming. The repercussions of chronic heat waves are particularly significant within forest reserves, and their effects on Ghana's Dormaa Central Municipality are explored in detail. Vegetation cover in Ghana has faced recurrent challenges from extreme heat waves, leading to diminished forested areas, heightened evapotranspiration rates, and instances of drought-induced water scarcity. To assess the severity of these impacts and devise proactive environmental management strategies, this study leverages the power of satellite remote sensing. Utilizing Landsat imagery, the study examines changes in Land Surface Temperature (LST) alongside the Normalized Difference Vegetation Index (NDVI) and Evapotranspiration (ET) within the Dormaa municipal area. Pearson correlation analysis is employed to uncover the intricate relationship between LST, vegetation health, and ET

within the Mpameso forest reserve. The study's compelling findings reveal that chronic heat waves predominantly affect the settlement areas surrounding the forest reserve, sparing the reserve itself from significant LST-related health impacts. This nuanced understanding underscores the importance of proactive conservation efforts and climate resilience planning, emphasizing the value of integrated approaches to safeguarding vital ecosystems in the face of mounting climate extremes.

Keywords: land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Chronic Heat Waves, Evapotranspiration (ET), Climate Change.

1. INTRODUCTION

Temperature is a major factor influencing plant development. Warmer temperatures expected as a result of climate change, as well as the possibility of more extreme temperature events, will have an impact on plant productivity. Pollination is one of the most sensitive phenological stages to temperature extremes across all species, and temperature extremes would have a significant impact on production during this developmental stage. The rate of plant growth and development is determined by the temperature around the plant, and each plant species has a temperature range that is represented by a minimum, maximum, and optimum. Changes in vegetation cover are a result of both environmental and biological factors. Several authors have found statistically significant correlations between temperature and vegetation indices (Kumar and Shekhar, 2015; Wang et al., 2015). Furthermore, soil temperature affects soil moisture levels as well as microbial function and productivity (Pregitzer and King, 2005). Based on field observations and remotely sensed data (Lapenis et al., 2014), it has been discovered that soil temperature levels vary greatly across landscapes depending on elevation and climate. However, as a result of climate change, soil temperatures have risen in many areas over the last century (IPCC, 2013). From 1906 to 2005, the average global surface temperature rose by 0.74 degrees Celsius (IPCC, 2007), and most models predict a rise of at least 1.5 degrees Celsius by the end of the century (IPCC, 2013). The increase in surface temperature over the last century has contributed to changes in vegetation phenology, species ranges, and community composition (Walther, 2010), and the projected global temperature increase will generally result in an increase in near-surface soil temperatures (Betts, 2001; Hinzman et al., 2005), affecting soil conditions and vegetation structure, composition, and growth (Rixen et al., 2008; Okkonen and Klve, 2010). This study looked at the impact of chronic heat waves, defined as temperatures of 30°C or higher in hilly areas and 40°C or higher in flat terrains, on the Mpameso forest reserve in the Dormaa Central Municipality of Ghana. Three different spectral indices were used. The following questions were specifically addressed: (i) How can the health of the Mpameso forest reserve be assessed? (ii) What is the relationship between Land surface temperature and the health of the forest reserve? A hypothesis was made that the health of the Mpameso forest reserve would show a negative correlation with increasing Land surface temperature (LST). There was also an expectation that the rate of Evapotranspiration (ET) of the Mpameso forest reserve would also have a negative correlation with Land surface temperature (LST).

2. MATERIALS AND METHODS

Study Area

The Mpameso forest reserve is located in the Bono region of Ghana. The majority of the total coverage of this Forest reserve is located in the Dormaa Central Municipality and the minor part in the Asutifi North district. It is located at latitude 7.07375 and longitude -2.87806. The estimated terrain elevation above the mean sea level of 260m. The Mpameso Forest Reserve serves as a pivotal study area in this research. This forest reserve, renowned for its ecological significance, encompasses diverse and unique ecosystems. It plays a critical role in maintaining regional biodiversity and supporting local communities' livelihoods. Over time, the reserve has faced environmental challenges, including the impact of climate change, making it an ideal site for investigating the effects of chronic heat waves. The findings here offer valuable insights into the conservation and management of this vital natural asset (GeoNames.org, 2022).

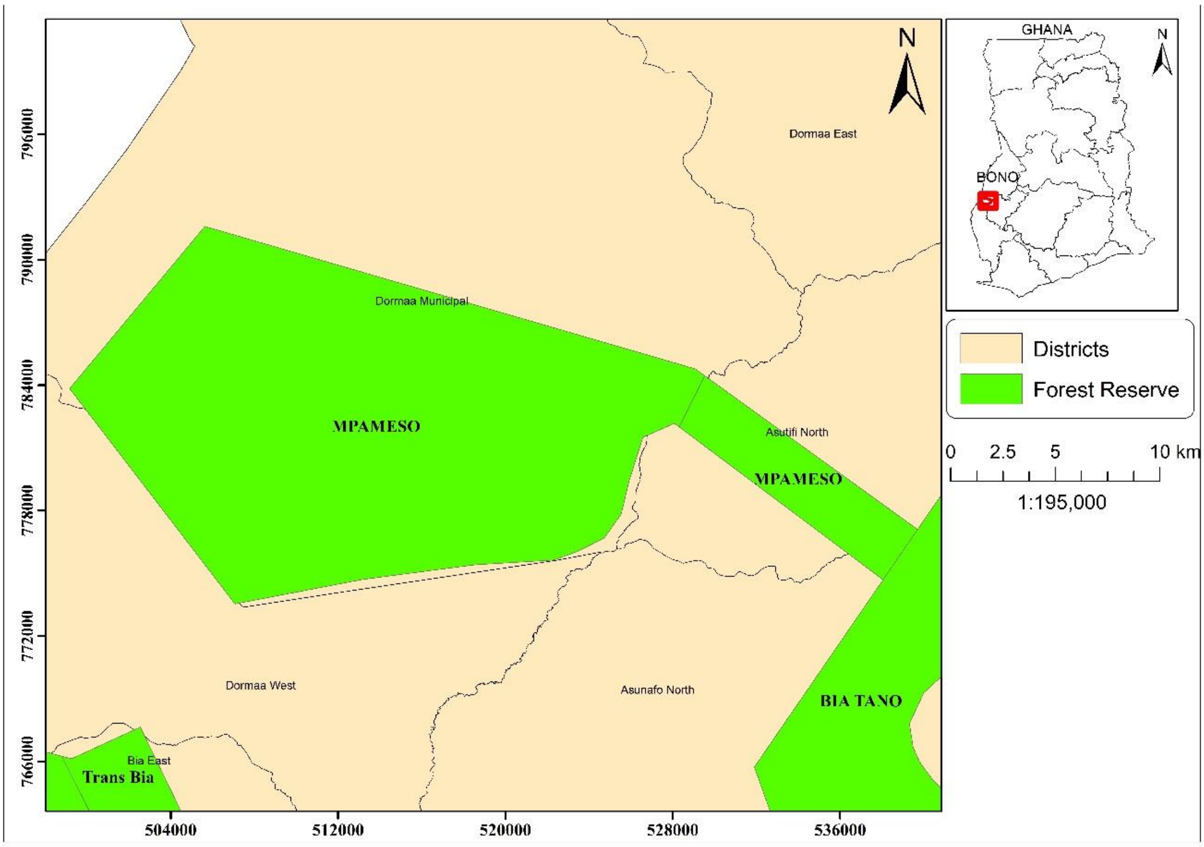


Figure 1 Map of the Study site

Materials Used

Satellite images were obtained for this study and QGIS software was used to process and analyse the satellite images. Table 1 shows the materials and data used in this study with their sources.

Table 1 Materials Used with their sources

	Material	Source
1	Evapotranspiration dataset (ET)	https://earlywarning.usgs.gov/fews/datadownloads/Continental%20Africa/Monthly%20ET%20Anomaly
2	Landsat dataset	earthexplorer.usgs.gov
3	Boundary of Forest Reserve	Open Street map
4	QGIS software 3.16	https://www.qgis.org/en/site/forusers/download.html

2. METHODS

Spectral Indices from Satellite Remote Sensing

In this study, Landsat 7 and 8 multispectral satellite images were used. A 10-year interval was used starting from 2002 to 2022. The near-infrared (NIR), Red, and Thermal bands were used to perform a spectral index calculation by using a raster calculator in QGIS 3.16. In order to determine the health of the forest reserve, The Normalized difference vegetation index (NDVI) was used. NDVI is a numerical indicator that uses the Red and near-infrared spectral bands of a satellite and is highly associated with vegetation content. High NDVI values correspond to areas that reflect more in the near-infrared spectrum. Higher reflectance in the NIR signifies denser and healthier vegetation. The NDVI was computed using Equation (1) for 2002, 2012 and 2022 (Figure 2).

$$NDVI = \frac{NIR-Red}{NIR+Red} \qquad (1)$$

Where NIR and Red are the Bands from the satellite image.
The NDVI was used to determine the health of the forest reserve. A higher spectral index signifies a healthy Forest.

Land Surface Temperature (LST) from Satellite Image

Land surface temperature was derived from geometrically corrected Landsat Thematic Mapper thermal infrared TIR, (band 6) images. The thermal infrared bands have a spatial resolution of 100 m for Landsat 8 TM images and 60 m for Landsat 7 ETM+ images. The raw digital numbers (DNs) were converted to radiances by applying the calibration coefficients (gains and offsets) specified in the Landsat handbook. Equation (2) was used to convert the digital number (DN) of Landsat7 ETM+ TIR band to spectral radiance and Equation (3) was used to Convert Spectral Radiance to Temperature Kelvin.
Conversion from Digital Number (DN) to Spectral Radiance (L):

$$L = L_{min} + (L_{min} - L_{\max}) x \ \frac{DN}{255} \qquad (2)$$

Where, L is the spectral radiance; L_{min} = 3.200 (Spectral Radiance of DN value 1);

Lmax = 12.650 (Spectral Radiance of DN value 255) and DN is the Digital Number
Conversion of Spectral Radiance to Temperature Kelvin:

$$T_{K}= \frac{K2}{In(\frac{K1}{L}+1\ )} \tag{3}$$

Where K1 is the calibration constant 1 (666.09), K2 is the calibration constant 2 (1282.71), T_k is the surface temperature in Kelvin and L is the spectral radiance
Conversion of Kelvin to Celsius using Equation (4)

$$Tc = Tk - 273.15 \tag{4}$$

where T_C is the temperature in degrees Celsius
To retrieve the land surface temperatures (LST), the brightness temperatures obtained were scaled using the emissivity of surface materials. Emissivity applied to urban surfaces ranges from 0.87 up to 0.97 with most values in the range of 0.92 to 0.95. The land surface temperature (LST) tool was modelled in QGIS 3.16. The model computes LST by combining NDVI, Proportion of Vegetation (Pv), Land surface emissivity, and Brightness temperature. The Red, NIR, and Landsat Thermal bands were used as input raster for the tool built in QGIS 3.16 by using the model builder. A relatively simple method was applied for retrieving the land surface emissivity (LSE) based on the Normalized Difference Vegetation Index (NDVI) applied to the NDVI Thresholds Method. This method obtains the emissivity values from the NDVI. Differentiation between vegetated and non-vegetated areas was made according to the normalized difference vegetation index values, which were computed from visible (0.63 – 0.69 mm) and near-infrared (0.76 – 0.90 mm) data of TM images based on the following equation:
The normalized Difference Vegetation Index was derived using Equation (1).
where *NIR* and *RED* are the spectral reflectance in the thematic mapper (TM) and enhanced thematic mapper plus (ETM+) Red and near-infrared bands.

Proportion of Vegetation

The Proportion of vegetation (Pv) was computed using Equation (5).

$$Pv = [\frac{NDVI-NDVImin}{NDVImax+NDVI\ min}]^2 \tag{5}$$

Where $NDVI_{MAX}$ and $NDVI_{MIN}$ are the maximum and minimum NDVIs

Land Surface Emissivity

Emissivity is the ratio of the radiant energy emitted from a real-world body to that emitted by a black body at the same temperature (Jensen, 2000).
Emissivity for the study was modelled using Equation (6).

$$\varepsilon = 0.004 * Pv + 0.986 \tag{6}$$

Where Pv is the proportion of vegetation

The emissivity-corrected land surface temperatures (LST) were then computed using the Equation (7).

$$LST = \frac{Tc}{1+(\lambda\sigma Tc/(hc)In\varepsilon)} \tag{7}$$

where λ is the effective wavelength (11.475 μm for band 6 TM/ETM+), σ is Stefan Boltzmann constant (1.38 x 10^{-23} J/K), h is Plank's constant (6.626 x 10^{-34} Js), c is the velocity of light at a vacuum (2.998 x 10^{-8} m/sc), ε is emissivity. The LST was computed for 2002,2012 and 2022 as shown in Figure 3.

Annual Evapotranspiration (ET)

This is the amount of water per day lost from the plant during transpiration. Temperature, wind speed, and climatic conditions contribute to evapotranspiration in Plants. The health of vegetation can be determined by the rate at which it loses water from the leaves. An annual Evapotranspiration data was downloaded from the worldClim data website and was used to extract the spatial distribution of annual ET in mm/day within the Mpameso Forest reserve as shown in Figure 4.

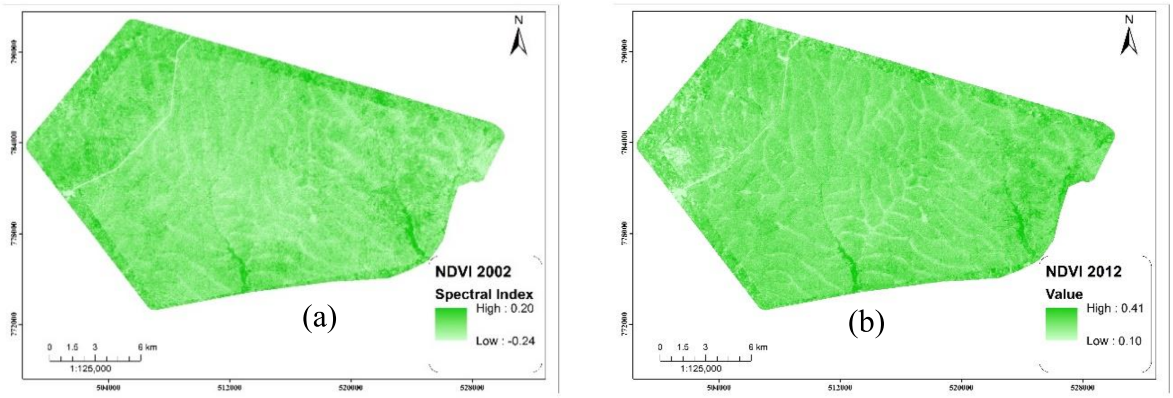
Correlation

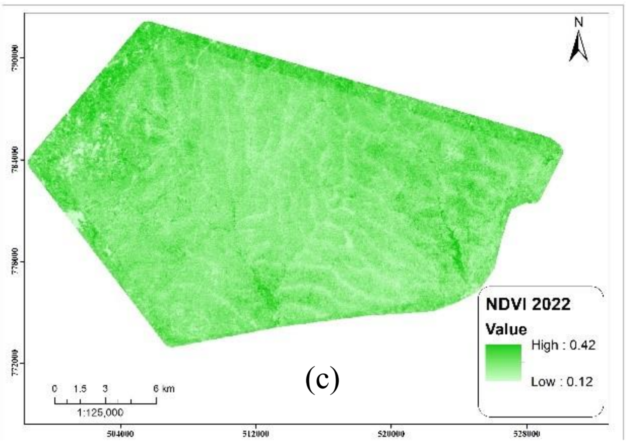
Twenty (20) Sample points (Figure 5) were selected inside the Mpameso Forest reserve to study the Dynamics of LST, NDVI and ET for 2002,2012 and 2022. A correlation was performed using the Three factors (NDVI, LST and ET) to determine the impact of LST on the health of the Forest Reserve (NDVI and ET). Using the Pearson correlation in the SPSS software, a 2-tailled correlation (at 0.01 and 0.05 significant levels) was performed.

3. RESULTS

Vegetation Health with NDVI

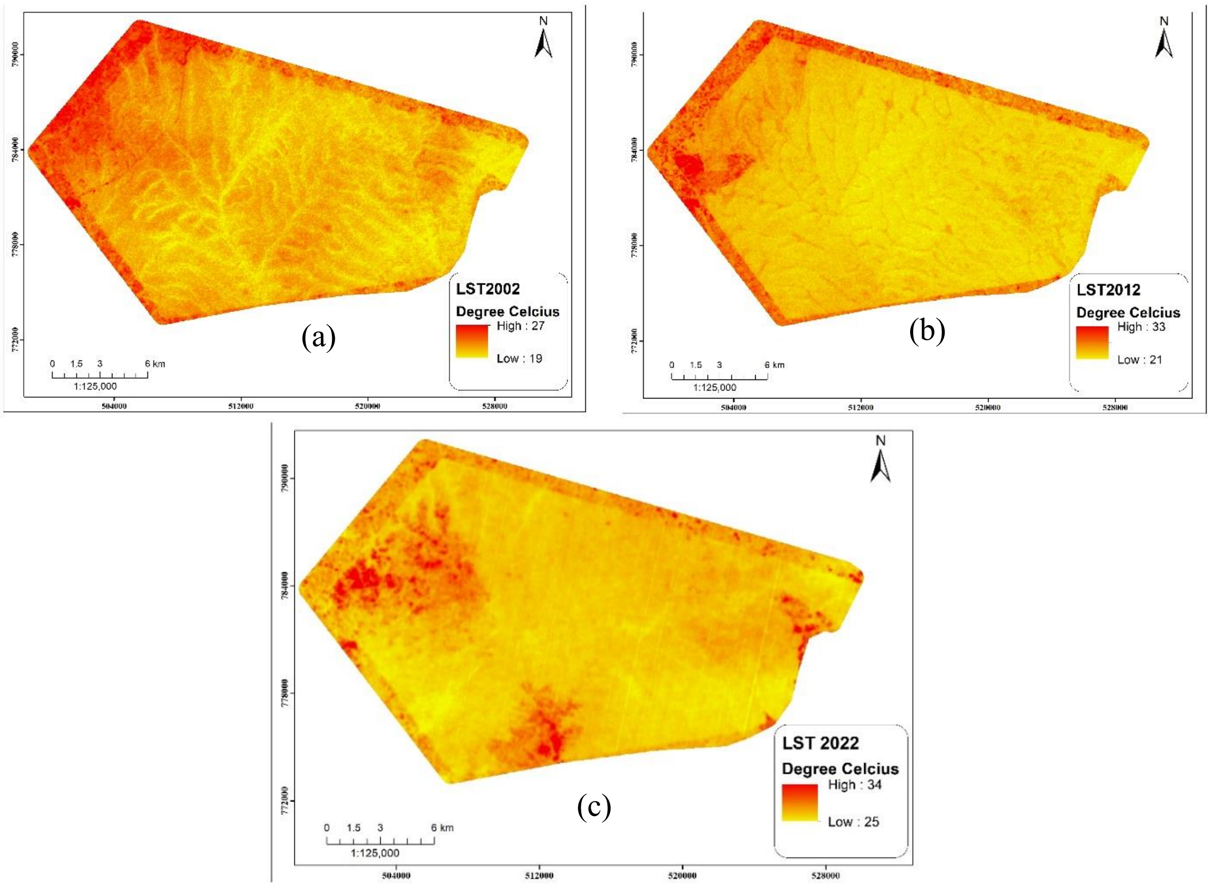
The recorded NDVI values for the sample points in the Forest reserve showed a significant increase in the health of the Forest from 2002 to 2022 as shown in Figure 2 and Figure 6.





(c)

Figure 2 NDVI for the Mpameso Forest Reserve (a) 2002, (b) 2012 and (c) 2022

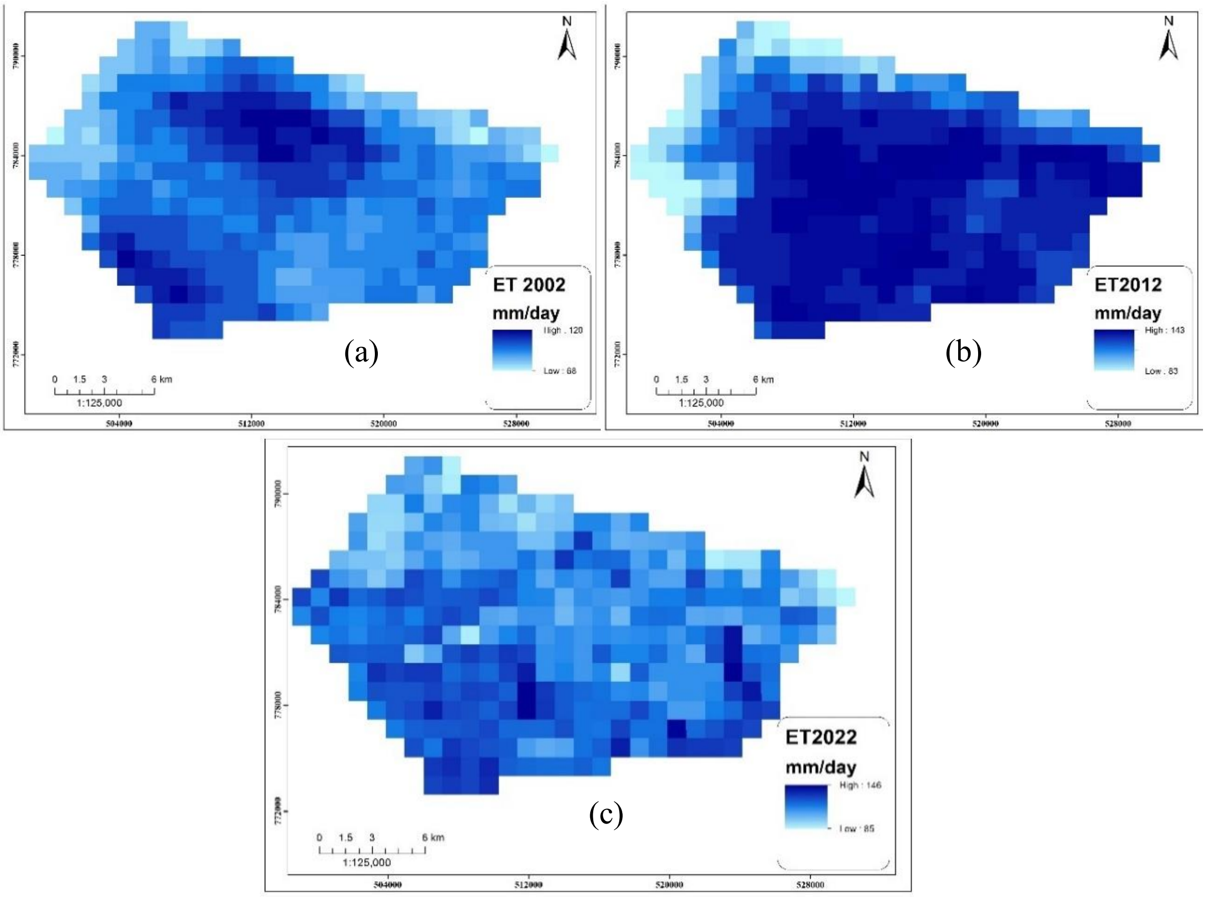


(a)

(b)

(c)

Figure 3 LST for the Mpameso Forest Reserve (a) 2002, (b) 2012 and (c) 2022



(a) (b) (c)

Figure 4 Spatial distribution of ET in the Mpameso Forest Reserve (a) 2002, (b) 2012 and (c) 2022

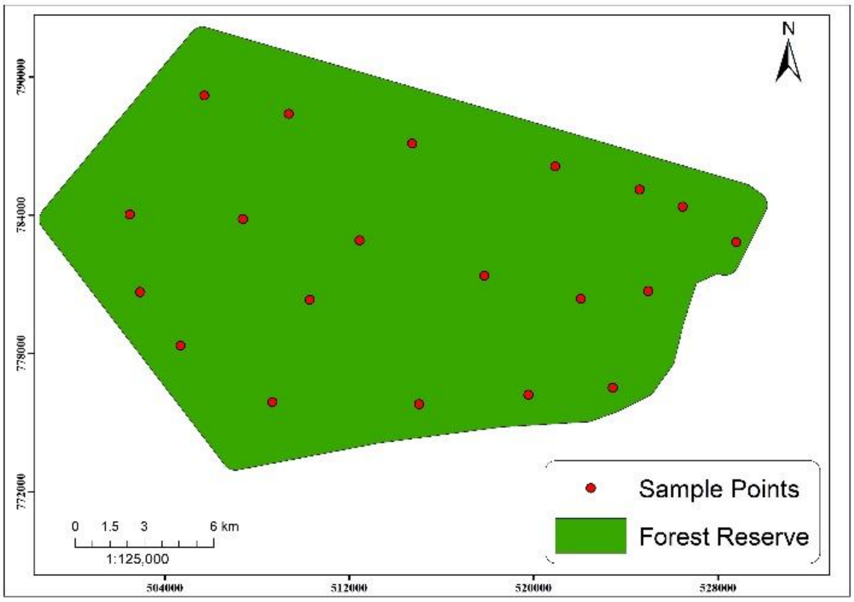


Figure 5 20 Sample points Within the Mpameso Forest Reserve

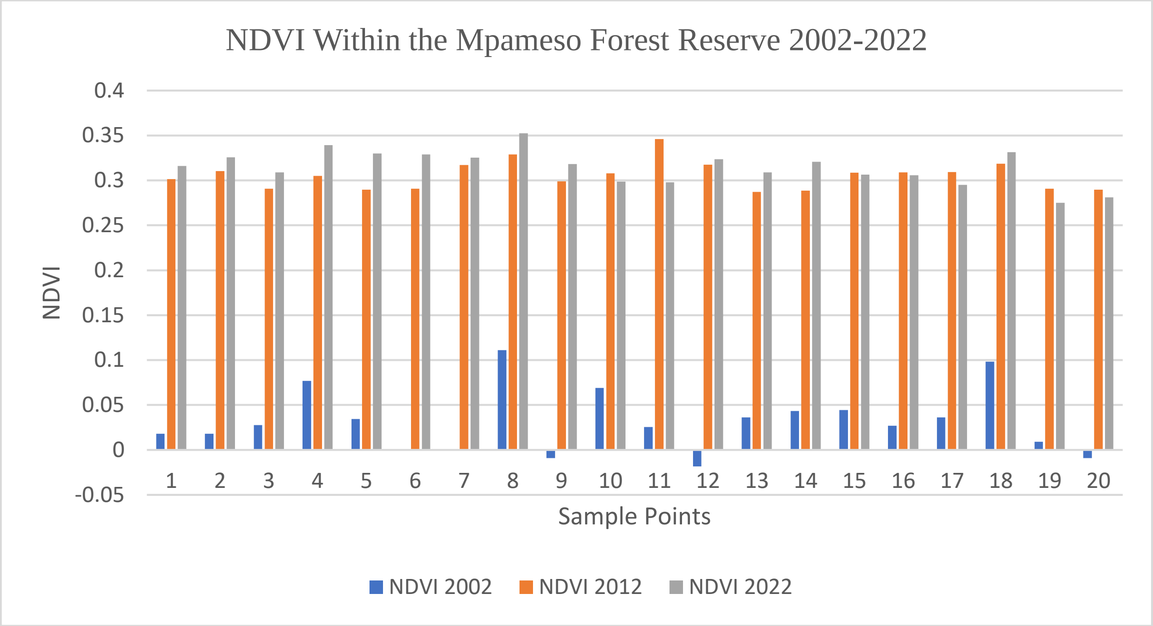


Figure 6 The health of the Mpameso Forest Reserve 2002-2022

Land Surface Temperature within the Mpameso Forest Reserve

A Land surface Temperature of less than 30^{0}C was observed within the Forest reserve from 2002 to 2022. This shows that the Chronic heat waves are not within the forest reserves but the settlements around the forest reserve. The samples recorded and Average LST of 21^{0}C for 2002, 22^{0}C for 2012 and 26^{0}C for 2022. This shows how LST is increasing within the forest reserve (Figure 7).

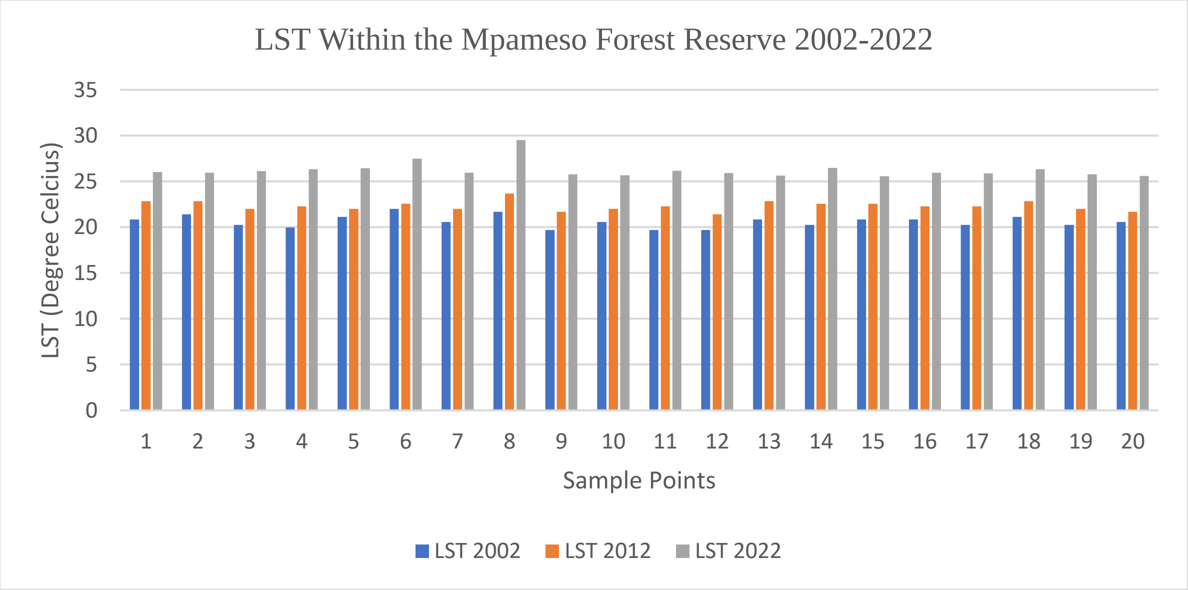


Figure 7 LST within the Mpameso Forest Reserve 2002-2022

Spatial Distribution of ET within the Mpameso Forest Reserve

The Sample Points Recorded the ET for 2002, 2012 and 2022. The results showed that, The ET has been increasing as the years increases (Figure 8).

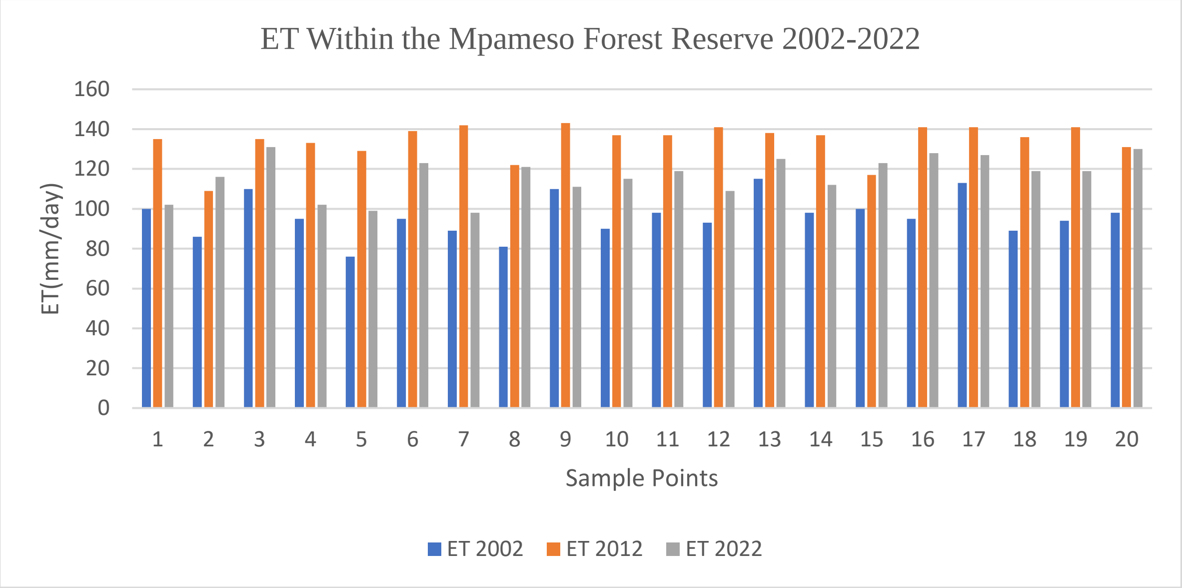


Figure 8 ET within the Mpameso Forest Reserve 2002-2022

Impact of Chronic Heat Wave on the Mpameso Forest Reserve

In 2002, a weak negative correlation was observed between LST and ET (R = -0.44) which is not significant at 0.01 and 0.05 significant level. A weak positive correlation was also observed between LST and NDVI. In 2012, a weak correlation was observed between LST and NDVI (R = 0.223) which was not significant at 0.01 and 0.05 significant level. A weak negative correlation was also observed between LST and NDVI (R = -0.487) at 0.05 significant level. In 2022, a good positive correlation was observed Between LST and NDVI (R=0.645) at 0.01 significant level. A very weak positive correlation was observed between LST and ET (R= 0.021) which was not significant at 0.01 and 0.05 significant level.

4. DISCUSSION

The assessment of chronic heat wave impacts on the Mpameso forest reserve, employing Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Evapotranspiration (ET) as key indicators, has yielded valuable insights into the environmental resilience of this vital ecosystem. Contrary to initial hypotheses, our findings suggest that there is no discernible presence of chronic heat waves within the Mpameso forest reserve during the study period. The analysis of LST, a critical parameter for understanding thermal conditions, revealed that the maximum LST value recorded in 2022 was within the range of 21°C to 26°C, indicating relatively mild thermal conditions. Furthermore, when assessing the impact of LST values ranging from 21°C to 26°Cover the two-decade study period (2002-2022), the effects on the forest reserve appeared to be significantly minimal. This unexpected result challenges the conventional assumption that rising LST inherently poses a threat to forest health. Our results further indicate a positive correlation between LST and the health of the Mpameso forest reserve. This counterintuitive relationship suggests that, within the observed temperature range, the forest appears to thrive. This resilience may be attributed to several factors, including the forest's adaptive capacity, suitable microclimatic conditions, and potentially effective local conservation efforts. Remarkably, the absence of chronic heat waves within the forest reserve is a reassuring finding, as these extreme temperature events can have devastating consequences on ecosystems, leading to increased stress, decreased productivity, and even forest dieback. Our study, however, identified heat waves in the settlement areas surrounding the forest reserve. This emphasizes the need for holistic conservation approaches that encompass not only the forest itself but also its surrounding buffer zones and neighboring communities.

Recommendations

1. Continuous Monitoring: While the absence of chronic heat waves is a positive revelation, it is crucial to maintain ongoing monitoring of LST and other environmental parameters within the Mpameso forest reserve. This will ensure early detection of any emerging threats and enable adaptive management strategies.
2. Buffer Zone Protection: Given the identified heat waves in the settlement areas surrounding the forest reserve, it is imperative to implement protective measures in these buffer zones. Community engagement and education programs can raise awareness about the importance of preserving the forest's ecological integrity.
3. Climate Resilience Planning: Develop and implement long-term climate resilience strategies for the Mpameso forest reserve. These strategies should consider potential future climate scenarios and prioritize actions that enhance the forest's ability to adapt to changing conditions.
4. Collaborative Conservation: Foster collaboration among local communities, governmental agencies, and conservation organizations to jointly manage and safeguard the forest reserve. This collaborative approach can ensure the sustainability of conservation efforts.
5. Further Research: Continue research efforts to explore the specific mechanisms that contribute to the forest's positive response to moderate LST. Understanding these mechanisms can inform targeted conservation practices that enhance ecosystem resilience. The absence of chronic heat waves within the Mpameso forest reserve is an encouraging finding. It underscores the forest's resilience and the effectiveness of conservation measures. However, proactive conservation and climate adaptation strategies remain essential to safeguard this valuable ecosystem in the face of evolving environmental challenges.

5. CONCLUSION

In this comprehensive study of the Mpameso Forest reserve in the Dormaa municipality, the findings have provided crucial insights into the dynamics of Land Surface Temperature (LST) and its impact on the forest's health. Contrary to initial assumptions, our analysis suggests that LST is not the primary factor contributing to the decline in the health of the Mpameso Forest reserve. The absence of a direct correlation between increasing LST and forest health loss challenges the conventional notion that rising temperatures invariably lead to adverse consequences for ecosystems. This unexpected result underscores the complexity of ecological responses to climate variables and highlights the potential resilience of the Mpameso Forest reserve to moderate temperature changes. Furthermore, the study offers an invaluable baseline for monitoring the influence of climate change on the forest reserve. While LST may not be the primary driver of health decline, the investigation serves as a critical starting point for comprehending the interplay of various climatic factors and their combined effects on forest ecosystems. It underscores the need for a holistic approach to climate impact assessment, considering multiple climatic variables in tandem. The notable increase in Normalized Difference Vegetation Index (NDVI) values within the forest reserve, even in the presence of rising LST and Evapotranspiration (ET), highlights the forest's capacity for adaptation and growth. This resilience is a positive indication of the forest's ability to withstand environmental challenges and thrive in the face of changing climatic conditions. One of the key findings is the identification of chronic heat waves, primarily located within the settlement areas surrounding the forest reserve, rather than within the reserve itself. This spatial distribution reinforces the significance of buffer zones and the need for conservation strategies that encompass not only the forest but also its immediate environs and neighboring communities. In conclusion, this study offers a nuanced understanding of the Mpameso Forest Reserve's response to environmental factors, particularly LST. While LST may not be the predominant driver of health decline, it provides a foundational understanding of the broader climate context. The forest's resilience and the absence of chronic heat waves within its boundaries are promising signs of its long-term sustainability. However, the study underscores the importance of ongoing monitoring, a holistic climate impact assessment, and collaborative conservation efforts to ensure the continued well-being of this vital ecosystem.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgments

The authors thank the technical support from the Remote Sensing and GIS Laboratory of the Department of Geospatial Sciences.

6. REFERENCES

1. Betts, R. A. (2001). Biogeophysical impacts of land use on present-day climate: near-surface temperature change and radiative forcing. Atmos. Sci. Lett. 2, 39–51. doi: 10.1006/asle.2001.0023.
2. GeoNames.org. (2022). https://www.geonames.org/2297899/mpameso-forest-reserve.html
3. Hinzman, L., Bettez,N., Bolton,W.R., Chapin,F.S., Dyurgerov,M., Fastie,C., et al.

(2005). Evidence and implications of recent climate change in northern Alaska and other arctic regions. Clim. Change 72, 251–298. doi: 10.1007/s10584-005-5352-2.
4. IPCC.(2007). Climate Change 2007: The Physical Science Basis. Contribution of WorkingGroupItotheFourthAssessmentReportoftheIntergovernmentalPanel on Climate Change, eds S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt et al (Cambridge: Cambridge University Press).
5. IPCC.(2013). Working Group I Contribution to the IPCC Fifth Assessment Report. Climate Change 2013: The Physical Sciences Basis Summary for Policymakers, eds T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung et al (Cambridge: Cambridge University Press).
6. Jensen, J.R., 2000. Remote sensing of the environment: An earth resource perspective. Prentice-Hall, New Jersey, pp: 181-243, 333-529.
7. Kumar, D., and Shekhar, S. (2015). Statistical analysis of land surface temperature–vegetation indexes relationship through thermal remote sensing. Ecotoxicol. Environ. Saf. 121, 39–44. doi:10.1016/j.ecoenv.2015.07.004.
8. Lapenis, A., Henry, H., Vuille, M., and Mower, J. (2014). Climatic factors controlling plant sensitivity to warming. Clim. Change 122, 723–734. doi: 10.1007/s10584-013-1010-2.
9. Okkonen, J., and Kløve, B. (2010). A conceptual and statistical approach for the analysis of climate impact on groundwater table fluctuation patterns in cold conditions. J. Hydrol. 388, 1–12. doi: 10.1016/j.jhydrol.2010.02.015.
10. Pregitzer, K., and King, J. (2005). "Effects of soil temperature on nutrient uptake," in Nutrient Acquisition by Plants, ed. H. BassiriRad (Berlin: Springer), 277–310. doi: 10.1007/3-540-27675-0_10.
11. Rixen, C., Freppaz, M., Stoeckli, V., Huovinen, C., Huovinen, K., & Wipf, S. (2008). Altered snow density and chemistry change soil nitrogen mineralization and plant growth. Arctic, Antarctic, and Alpine Research, 40(3), 568–575. https://doi.org/10.1657/1523-0430(07-044.
12. Wang, C., Cao, R., Chen, J., Rao, Y., and Tang, Y. (2015). Temperature sensitivity of spring vegetation phenology correlates to within-spring warming speed over the Northern Hemisphere. Ecol. Indic. 50, 62–68. doi: 10.1016/j.ecolind.2014.11.004.
13. Walther, G.-R. (2010). Community and ecosystem responses to recent climate change.Philos.Trans.R.Soc.BBiol.Sci.365,2019–2024.doi:10.1098/rstb.2010.0021.