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## Analysis of spatio-temporal variability of temperature, relative humidity and temperature humidity index in Naivasha Sub-county, Kenya

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### Abstract

The aim of the study was to understand the environmental conditions impacting the reproductive performance of Sahiwal cattle, focusing on temperature, relative humidity, and relative humidity index (RHI). These factors significantly influence reproductive rates, highlighting the importance of spatio-temporal variability studies for informed herd management decisions. This study analyzed climate variability trends from 1998 to 2019 at the Kenya Agricultural and Livestock Research Organization (KALRO) Dairy Research Institute (DRI)-Naivasha, in Malewa Ward, Naivasha Sub-County, Kenya. Daily minimum and maximum temperature (T) and relative humidity (RH) data sourced from the Kenya Meteorological Department were utilized. The Temperature-Humidity Index (THI) was computed using the THI equation developed by Mader. Time series analyses, including the Mann-Kendall test and Sen's slope estimates, were employed to assess seasonal variability. Results indicated significant decreasing trends in temperature across all the four seasons studied (DJF, MAM, JJA, and SON), with rates of cooling at -0.0625, -0.0175, -0.0125, and -0.0342 °C per year, respectively. In contrast, relative humidity showed statistically significant increases in all seasons, with rates of +0.5977, +0.999, +1.4493, and +1.0499 for DJF, MAM, JJA, and SON, respectively. Seasonal THI exhibited significant decreases in DJF and JJA, potentially impacting livestock reproductive performance. These findings are crucial for policymakers to create adaptation and mitigation methods to address climate change effects on livestock and livelihoods.

**Key words:** Relative humidity, temperature, THI, spatio-temporal, trends.



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## INTRODUCTION

Climate variability poses a significant threat to pastoral and agro-pastoral livelihoods, particularly within the agricultural sectors globally, as evidenced by the increased frequency of extreme weather events (FAO, 2004; Muoki, 2020). This variability, characterized by changes in temperature (the measure of heat in the atmosphere) and relative humidity (the amount of moisture in the air relative to its maximum capacity), directly influences livestock growth and development. The ongoing warming of the global atmosphere, marked by more frequent heat waves, is pushing ambient temperatures beyond the tolerance limits of both humans and livestock across various production systems. For instance, in Nakuru County, the livelihoods of many communities are intricately linked to the biophysical environment, making them particularly vulnerable to climatic fluctuations (Bett et al., 2009). Addressing the adverse impacts of heat stress on livestock production and reproduction is essential to ensure livelihood security for often poor and marginalized farmers. Understanding the spatio-temporal variability (the changes in environmental conditions over both space and time) of temperature, relative humidity, and THI (Temperature-Humidity Index) is crucial in Naivasha Sub-County, Kenya. Analyzing these trends will provide useful insights into climate impacts on agricultural productivity and livestock health, enabling better adaptation strategies for local farmers.

## LITERATURE REVIEW

Africa is at higher risk of experiencing the effects of climate change as a result of its heavy dependence on rainfall for agriculture and livestock production (IPCC, 2014; Serdeczny et al., 2015). Predicting the consequences of climate change on livestock is crucial, as highlighted by Lobell et al. (2011), which requires reliable tools, data, and models. Campbell et al. (2011) predict that at least 22 per cent of global livestock production areas will be negatively impacted by 2050. For example, livestock production in the United States of America has already been affected by hot summers (Hahn et al., 1992) and reduced dairy cow performance (Klinedinst et al., 1993). Similarly, Muxi et al. (2022) noted that livestock contributes around 40 per cent of global agricultural gross domestic product (GDP), while

Campbell et al. (2011) found significant climate risks to livestock areas in California. Godde et al. (2020) affirm that climate-related risks will disproportionately affect regions like Africa, where heat stress will intensify due to climate change. In India, Smita (2007) observed that heat stress has worsened for dairy animals, reducing the regions where high-yielding cattle can thrive. In Africa, a survey of over 5,000 farmers revealed that dairy income and herd size are closely tied to climate conditions, with warming temperatures reducing net livestock income (Robert & Sugno, 2013).

Climate change is more severely felt at local scales, especially in developing countries where people rely heavily on natural resources (Bello, 1997). Increased greenhouse gases are expected to change global temperature and rainfall patterns, leading to reduced food and fodder production, which will hit Africa hardest, given its frequent droughts and heavy reliance on rain-fed agriculture (Dinar et al., 2008). Moenga (2010) reveal that Kajiado has experienced significant climate changes over 30 years, affecting livestock production. However, these studies did not fully address the impacts of the temperature-humidity index. Research on temperature trends in East Africa (Kinguyu et al., 2000) shows rising temperatures and increasing stress on cattle reproduction. Models predict a 3°C to 4°C temperature rise in the region by the end of the 21st century, outpacing global averages (IPCC, 2007). Understanding these trends is essential for mitigating the impacts of climate change on livestock and supporting ecosystems.

## METHODOLOGY

This study was carried out at the Kenya Agricultural and Livestock Research Organization (KALRO), Dairy Research Institute (DRI)-Naivasha in Malewa Ward located in Naivasha Sub-County of Nakuru County, Kenya, approximately 92.8 kilometres by road North West of Nairobi. The ward lies between latitude -0.717178 and longitude 36.431026. The study area covers an area of 9,462 km<sup>2</sup> (2,338,111 acres) (NCG, 2013-2017). The altitude of the study area ranges from 1890 to 1898m above mean sea level (KIFCON, 2004). The study area experiences a tropical savannah type of climate characterized by a bimodal rainfall pattern comprising long and short

rainy seasons. The long rainy season is experienced in April through June, while the short rainy season is experienced in October, November and December. The climate is warm and temperate, with an average temperature of 16.8 °C. The number of rain days ranges from 100 – 120 days per year, with an average rainfall ranging from 1,000 to 1,250 mm. This rainfall is adequate to support healthy vegetation throughout the year (KIFCON, 2004). The community of the study area depends on agriculture in the broader sense, comprising crop husbandry, including forestry (fruit trees), and livestock husbandry, including fisheries, as a means of their livelihoods. Naivasha Sub-County is endowed with a high capacity for livestock production, where the main livestock reared include cattle, poultry, sheep and goats. Most cattle are reared on an extensive grazing system CDIDP, (2021). The dairy sector is the largest livestock enterprise in Naivasha subcounty. Annually, the dairy industry generates about 1.2 billion Kenya shillings from milk sales in the sub-county. Other smaller enterprises in the livestock subsector include poultry, beef, honey, hides, and skin. Naivasha sub-county has a lot of potential in the horticulture industry, especially in the floriculture sub-sector. The county generates about 23 billion shillings annually from the horticulture subsector, where half of it comes from Naivasha sub-county. Floriculture and fishing are the main industries in Naivasha (County Government of Nakuru, 2021).

This study employed observed climate data comprising daily minimum and maximum temperature (oC) and relative humidity (%) for the period 1998 to 2019. The observed meteorological data were obtained from the Kenya Meteorological Department (KMD). Data were assessed for data quality to determine data homogeneity or consistency and estimate missing data values in the respective time series. The temperature-humidity index (THI) takes into account both humidity and temperature to estimate the level of heat stress cows will experience based on environmental conditions. The Temperature-Humidity Index (THI) values for each day were computed using an equation that combined the effects of ambient daily temperature and humidity data sets collected from the Kenya Meteorological Department to assess the heat load

intensity for the period 1998-2019. The THI equation that was developed by Mader T. (2006), given in equation 1, was used in this study.

$$THI = 0.8T_{db} + RH (T_{db}-14.4) + 46.4$$

..... (Equation 1)

Where THI is the temperature humidity index, T is ambient or dry-bulb air temperature (°C), DB is the dry-bulb, and RH is relative humidity (%). The relative humidity, ambient temperature and the computed THI's in equation 1 were subjected to time series analyses to determine the trend and the variability inherent in them using the Mann-Kendall test (Kendall, 1975) and Sen's slope estimates Application (MAKESENS, 2002). These approaches are described in the subsections below. The Mann-Kendall statistical test, as described by Kendall (1975), was used to assess the trend in temperature, relative humidity, and THI values to determine whether the values were increasing or decreasing over time and whether the trend was statistically significant. While other statistical trend tests exist, this methodology was adopted owing to its flexibility in application to varying circumstances. Being nonparametric in nature implies that data does not have to be homogeneous and normally distributed. Furthermore, the tests can still be performed even when there are missing values in the data set. In performing this test, the first stage entailed determining the sign of all n(n-1)/2 possible differences of temperature, humidity and THI, X<sub>j</sub>-X<sub>k</sub>, where j>k, by selecting sign (X<sub>j</sub>-X<sub>k</sub>) as an indicator that takes on values 1, 0, or -1 according to the sign of X<sub>j</sub>-X<sub>k</sub> as given below.

$$sgn(x_j - x_k) = \begin{cases} 1, & \text{if } x_j - x_k > 0 \\ 0, & \text{if } x_j - x_k = 0 \\ -1, & \text{if } x_j - x_k < 0 \end{cases}$$

..... (Equation 2).

For each comparison pair, a "+1" score was assigned if the latter value was greater than the former value. If the latter value was lower than the former value, then the comparison was assigned a "-1" score. All scores were then summed up to calculate the test statistic, S, given in Equation 3.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \dots\dots\dots$$

..... (Equation 3)

Where: Xj is the sequential value and n is the length of the data set. Equation 3 represents the number of positive differences minus the number of negative differences in the temperature, relative humidity and THI values. Positive S values indicated that temperature, relative humidity and THI obtained later in time tended to be larger than observations made earlier, while negative S values indicated that observations made later in time tended to be smaller than observations made earlier. A positive S value signified an increasing trend, and a negative S value meant that the trend was decreasing. The variance of the S-statistic was then computed using Equation 4.

$$\text{VAR}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^g t_p(t_p-1)(2t_p+5)] \dots\dots\dots$$

..... (Equation 4)

Where g is the number of tied groups and tp is the number of observations in the pth group. From equation 4, the Mann-Kendall (MK) test statistic, Zmk, was computed using equation 5.

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \dots\dots\dots$$

..... (Equation 5)

A positive value of Zmk indicated that the temperature, relative humidity and THI tended to increase with time, while a negative value signified decreasing temperature, relative humidity and THI with time. The Mann-Kendall test (MAKESENS-template) was used jointly to get both the P and the Z values for temperature, relative humidity and THI data. The temperature, relative humidity and THI values for the period 1998 to the year 2019 were tabulated and subjected to the Mann-Kendall test (MAKESENS template) to give the Z-score. This data comprised tabulated THI values for the period 1998 to the year 2019. The significance of the trend was assessed statistically by using Z-value. A

positive Z-value indicated an increasing trend, while a negative Z-value indicated a declining trend. MAKESENS performed calculations at four different significance levels, including  $\alpha=0.001$ , 0.01, 0.05 and 0.1. Here, the significance level of, for instance, 0.1 meant that there was a 10 per cent probability that we may make a mistake when rejecting H0 (null hypothesis).

The following symbols based on the MAKESENS template were employed to indicate the levels of statistical significance of the trends: \*\*\*If trend at  $\alpha = 0.001$  level of significance, \*\*If trend at  $\alpha = 0.01$  level of significance, \*If trend at  $\alpha = 0.05$  level of significance, + If trend at  $\alpha = 0.1$  level of significance and blank if  $\alpha > 0.1$  level of significance. The nonparametric Sen's method (Gilbert, 1987) method was adopted to estimate the magnitude of the trends in the long-term temperature, relative humidity and THI as recommended by Agarwal et al. (2021). This method was considered to be the best for detecting linear relationships as it is not affected by outliers in the data (Ray et al., 2021). Equation 6 was used to estimate each individual slope (Qi).

$$Q_i = \frac{Y_j - Y_i}{j - i} \dots\dots\dots$$

..... (Equation 6).

Where  $i = 1$  to  $n - 1$ ,  $j = 2$  to  $n$ , Yj and Yi are temperature, relative humidity or THI data values at time j and i ( $j > i$ ), respectively. If, in the time series, there are n values of Yj, estimates of the slope will be  $N = n(n - 2)/2$ . The slope of Sen's estimator is the mean slope of such slopes' N values given by equation 7.

$$Q_{ij} = \begin{cases} \frac{Y_j - Y_i}{j - i} & \text{if } n \text{ is odd} \\ \frac{1}{2} \left( Q \frac{N}{2} + Q \left[ \frac{N+2}{2} \right] \right) & \text{if } n \text{ is even} \end{cases} \dots\dots\dots$$

..... (Equation 7).

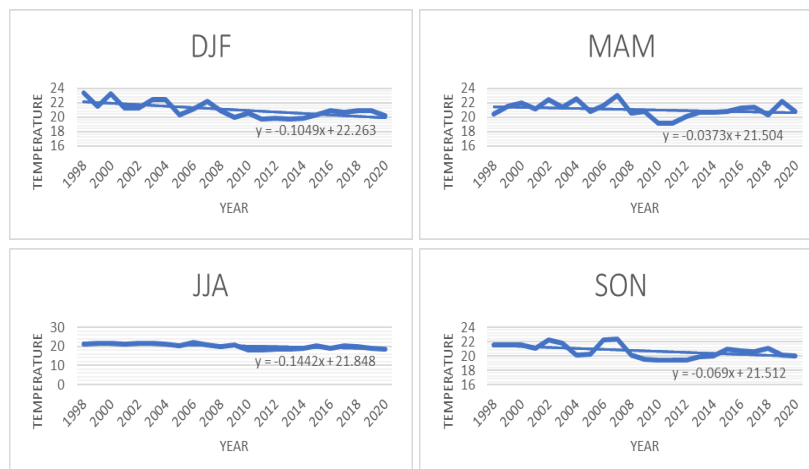
The unit of Sen's slope (Qi) is the slope magnitude per year. The positive (Qi) values indicate an increasing trend, while the negative Qi values signify a negative trend in temperature, relative humidity, and THI data.

**RESULTS AND DISCUSSION**

**Temporal Variability of Seasonal Temperature**

Figure 1 presents the time series plots of mean seasonal air temperature for December, January,

February (DJF), March, April, May (MAM), June, July, August (JJA) and September, October, November) SON seasons over the period 1998-2019.



**Figure 1: -Temporal variability of Seasonal Temperature for DJF, MAM, JJA and SON for Naivasha for the period 1998 – 2019**

From Figure 1, it is observed that the mean seasonal temperature across the four seasons studied depicted decreasing trends. Table 1 below shows results for

the Mann Kendall and Sen’s slope tests of these observed trends.

**Table 1: Mann-Kendall and Sen’s Slope Tests of Trends of Seasonal Temperature over the Study Area for DJF, MAM, JJA and SON Seasons for 1998 – 2019**

TREND STATISTICS – TEMPERATURE						
Time Series	First Year	Last Year	N	Mann-Kendall Trend		Sen's Slope Estimate
				Test Z	Level of Significance	
DJF	1998	2019	22	-3.5037	***	-0.0625
MAM	1998	2019	22	-2.4747	*	-0.0175
JJA	1998	2019	22	-2.4672	*	-0.0125
SON	1998	2019	22	-3.7831	***	-0.0342

Notes: - n – number of years; \*  $P \leq 0.05$ ; \*\*\*  $P \leq 0.001$ ; Test Z-Mann Kendall Z Statistic

Among the four seasons studied, JJA recorded the lowest decrease in temperature, while DJF recorded the highest decrease in temperature. The decreasing trends in temperature for the four seasons studied (DJF, MAM, JJA and SON) were statistically significant, and the rates of cooling of seasonal temperature during the DJF, MAM, JJA and SON seasons were -0.0625, -0.0175, -0.0125 and -0.0342 °C per year, respectively (Table 1). The declining temperature over Naivasha could be attributed to

climate variability mode that is often embedded in the change occasioned by a variety of factors, such as changes in atmospheric composition, notably the atmospheric aerosol loading and/or changing local weather patterns. Increasing aerosol concentration in the atmosphere causes atmospheric cooling while rising Lake Naivasha level could strengthen the lake breeze effect, thus lowering the surface air temperature. Aerosols significantly influence microclimates by scattering and absorbing solar

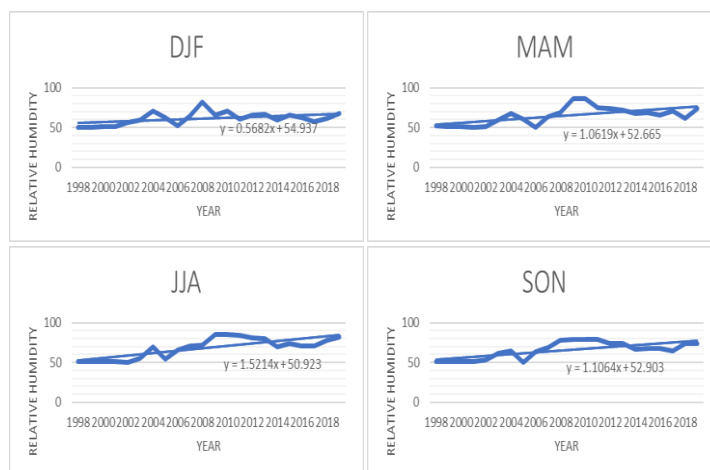
radiation, which alters the energy balance and can lead to local cooling. They act as cloud condensation nuclei, affecting cloud formation and precipitation patterns, thereby impacting local temperature and vegetation dynamics. Similar observations have also been made by several studies (Mutungwa et al., 2011; Odongo et al., 2015; Kathleen et al., 2011).

There has been an influx of water in the Rift Valley lakes of Kenya, including Lake Naivasha, where lake levels have continually been rising, especially during the period under study. The influx of water may, thus, contribute to lowering the temperature of the area. Other studies have also indicated that the mean temperature for Naivasha has decreased (Christensen et al., 2007; Darkoh & Mbaiwa, 2014). Other factors that could have contributed to the decreasing air temperature in Naivasha include the heightened campaign for reforestation and afforestation in the sub-county. The increasing tree cover results in lowering air temperatures as well by altering the surface characteristics of the land in the study area and increases evapotranspiration, which expends heat energy and results in the cooling effect. Vegetation, particularly trees, plays a vital role in

regulating temperature by providing shade and evaporating water through transpiration, which cools the surrounding air (Orindi et al., 2007). It has been observed elsewhere that the Earth's average annual temperature is rising, but not necessarily in every single location during all seasons (Kizza et al., 2009). Human beings, as well as livestock, may face challenges in extremely cold environments through a compromised immune system that makes them more susceptible to diseases, notably respiratory infections. Illnesses and cold stress can reduce cattle feed intake, weight gain, and milk production. In addition, cold temperatures can affect the reproductive performance of cattle since it leads to delayed puberty, irregular estrous cycles, decreased fertility, and increased calving intervals (Odongo et al., 2015).

**Temporal Variability of Seasonal Relative Humidity**

Figure 2 shows the variability of mean seasonal relative humidity in Naivasha Sub County during the DJF, MAM, JJA and SON seasons over the period 1998 to 2019.



**Figure 2: Variability of Mean Seasonal Relative Humidity for Naivasha for the Period 1998-2019**

Figure 2 shows that there were increasing trends of relative humidity during the study period across study seasons. However, the slopes of the trend lines varied with seasons. Table 2 shows the Mann-

Kendall and Sen's slope test results for the observed trends of relative humidity (RH) for the DJF, MAM, JJA and SON seasons for the period 1998-2019.

**Table 2: Mann-Kendall and Sen’s Slope Tests of Trends of Seasonal Relative Humidity over the Study area for the DJF, MAM, JJA and SON Seasons for the Period 1998 – 2019**

TREND STATISTICS - RELATIVE HUMIDITY						
Time Series	First Year	Last Year	N	Mann-Kendall Trend		Sen's Slope Estimate
				Test Z	Level of Significance	Q
DJF	1998	2019	22	2.4250	*	0.5977
MAM	1998	2019	22	2.6235	**	0.9990
JJA	1998	2019	22	3.2441	**	1.4493
SON	1998	2019	22	2.7927	**	1.0499

Notes: n – number of years; \*  $P \leq 0.05$ ; \*\*  $P \leq 0.01$ ; Test Z-Mann Kendall Z Statistic

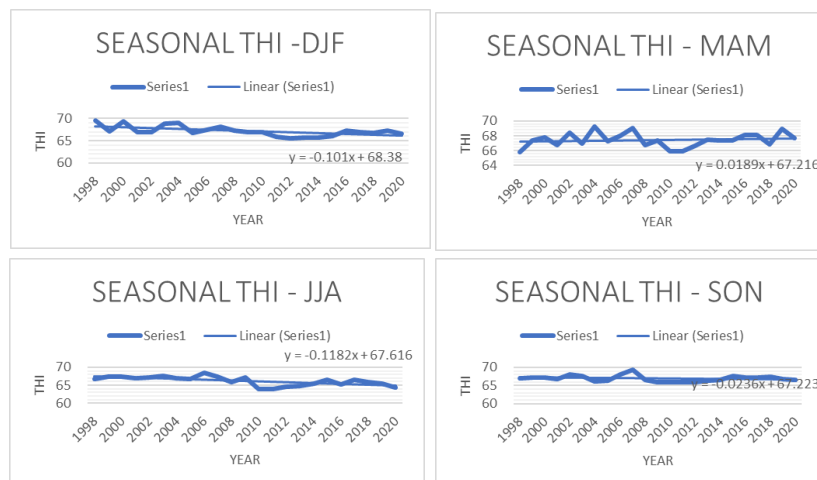
The findings of the Mann-Kendall and Sen's slope tests indicate statistically significant increasing trends in the seasonal relative humidity across the four study seasons (DJF, MAM, JJA and SON). However, the rates of increase in the trends varied with the season at the rate of +0.5977, +0.999, +1.4493 and +1.0499 for DJF, MAM, JJA and SON seasons, respectively. The JJA season recorded the highest rate of increase in relative humidity, while DJF recorded the lowest rate of increase in the seasonal relative humidity. The observed rate of increase in the trend of seasonal relative humidity could be attributed to the fact that relative humidity is influenced by moisture availability at the surface to be evaporated and air temperature. It tends to be high during the wet seasons and low during the dry seasons (Karimi, 2013). Given the neighbourhood of Lake Naivasha, there will be enhanced evaporation from the lake, leading to increased relative humidity in the atmosphere. High humidity can enhance plant growth and development by increasing transpiration rates, but it may also promote diseases like rust and blight in susceptible crops while affecting produce quality. In livestock, high humidity exacerbates heat stress, leading to reduced feed intake and reproductive performance while also increasing the risk of respiratory diseases and feed spoilage, necessitating adjustments in management practices to mitigate these challenges. Humid environments coupled with a concomitant temperature can also increase the incidence of fungal attacks in livestock, such as dermatitis and other fungal infections in cattle. These conditions thrive in moist conditions and can cause discomfort and reduced productivity in

affected animals. This is in line with Ochieng, J. (2016), who stated that temperature is the foremost factor influencing relative humidity (RH).

**Temporal Variability of Temperature-Humidity Index**

Temperature-Humidity Index ranges can have significant implications on livestock productivity (Ravagnolo, O. 2000). High THI values can cause heat stress in livestock, which can lead to a range of negative impacts on their health, welfare, reproductivity, and productivity. When cattle experience heat stress, they may have reduced feed intake, which subsequently leads to lower nutrient intake, reduced weight gain, reduced milk production and lower reproduction performance (Silva et al., 2019). Figure 3 presents the trends in seasonal temperature humidity index (THI) for DJF, MAM, JJA and SON seasons for the period 1998-2019. Figure 3 depicts decreasing trends in THI for the study seasons (DJF, JJA and SON) over the period 1998-2019, while the MAM season exhibited an increasing trend in THI. The observed THI varied with season and ranged from 66.3 to 67.4. The highest THI was observed during MAM, while the lowest was experienced in JJA. The result from this study revealed that the THI values during the study period were within the thermal neutral range that is considered safe for cattle (THI <66.3 – 67.4), according to Silva et al. (2021). This indicates that the range of THI experienced in the Naivasha sub-county was conducive to cattle production and performance.





**Figure 3: - Seasonal Trends of Temperature Humidity Index (THI) in Naivasha for the Period 1998-2019**

Table 3 presents the results of Mann Kendall and Sen's slope tests for seasonal THI for the DJF, MAM, JJA, and SON seasons from 1998 to 2019.

**Table 3: Mann-Kendall and Sen's Slope Tests of Trends of Seasonal Temperature Humidity Index over the Study area for the DJF, MAM, JJA and SON Seasons for 1998 – 2019**

TREND STATISTICS FOR TEMPERATURE HUMIDITY INDEX						
				Mann-Kendall trend		Sen's Slope Estimate
Time series	First-year	Last Year	N	Test Z	Level of Significance	Q
DJF	1998	2019	22	-2.72	**	-0.077
MAM	1998	2019	22	0.58		0.000
JJA	1998	2019	22	-2.38	*	-0.067
SON	1998	2019	22	-0.37		0.000

Notes: n – number of years; \*  $P \leq 0.05$ ; \*\*  $P \leq 0.01$ ; Test Z-Mann Kendall Z Statistic

Table 3 shows significant decreasing trends in the seasonal temperature-humidity index across two study seasons, namely DJF and JJA, while the MAM season showed an insignificant increasing trend. SON season exhibited an insignificant decreasing trend in THI. The rate of decreasing trends was -0.077 and -0.067 per year for DJF and JJA, respectively. The significant decrease in the temperature-humidity index observed in the DJF and JJA seasons could be attributed to the observed increase in relative humidity associated with the observed decreasing temperature during the study period. Further, the decrease in THI may also be attributed to the increasing conversion of natural land cover to the irrigated agricultural fields in Naivasha

and/or urban land cover, which could have altered the local microclimate through enhanced evapotranspiration and humidity, contributing to changes in THI (West, J. 2003). Although the trends in the temperature-humidity index (THI) during the MAM and SON seasons were insignificant, monitoring and preparedness remain essential for livestock management, as minor fluctuations can affect animal welfare and productivity. Livestock managers should implement adaptive strategies, ensure adequate nutrition and water availability, and focus on long-term planning to enhance resilience against potential heat stress and climate variability.

## CONCLUSIONS AND RECOMMENDATION

**Conclusion:** This study aimed to examine the spatio-temporal variability of temperature relative humidity and THI trends in Naivasha Sub-County, Kenya, in the past two decades (1998-2019). The conclusion of this study is that even though seasonal temperatures have been increasing in other parts, both the maximum and minimum temperatures have slowly decreased over time. The study findings conclude that the mean seasonal temperature across the four seasons studied DJF, MAM, JJA, and SON depicted decreasing trends. Among the four seasons studied, JJA recorded the lowest decrease in temperature, while DJF recorded the highest decrease in temperature. The decreasing trends in temperature for all the seasons studied were statistically significant. The Mann-Kendall and Sen's slope tests results indicate statistically significant increasing trends in the seasonal relative humidity across the four study seasons (DJF, MAM, JJA and SON). However, the rates of increase in the trends varied with the season at the rate of +0.5977, +0.999, +1.4493 and +1.0499 for DJF, MAM, JJA and SON seasons, respectively. The JJA season recorded the highest rate of increase in relative humidity, while DJF recorded the lowest rate of increase in the seasonal relative humidity. There were significant decreasing trends in the seasonal THI across two study seasons, namely DJF and JJA, while the MAM season showed an insignificant increasing trend. SON season exhibited an insignificant decreasing trend in THI. The rate of decreasing trends was -0.077 and -0.067 per year for DJF and JJA, respectively. The study findings reveal a decreasing trend in mean seasonal temperature across all four seasons, with a significant increase in relative humidity, especially during the JJA season. While the decrease in temperature may benefit crop

production by reducing heat stress, the accompanying rise in humidity could increase the risk of fungal diseases and exacerbate heat stress in livestock, necessitating proactive management strategies to optimize agricultural productivity and ensure livestock welfare.

**Recommendation:** There is scanty research explicitly focusing on spatio-temporal variability of temperature, relative humidity and temperature humidity index in Naivasha sub-County, Kenya. It is important to incorporate spatiotemporal variability of temperature, relative humidity and temperature humidity index more in the livestock's development strategies, planning and product development, incorporating new learning about climate change impacts and emerging opportunities (Dodman & Mitlin, 2013; Mustelin et al., 2010). The findings of this study will guide the formulation of policy options, interventions, and essential support necessary for the sustainable management of livestock production systems. It will also provide the information needed to support the development of adaptation strategies to the impacts of climate change by development actors such as the Ministry of Fisheries, Agriculture and Livestock National Drought Management Authority (NDMA) and relevant Non-Governmental Organizations (NGOs). The study will assist pastoralists and other stakeholders, including policymakers, with technical guidance on long-term breed multiplication and conservation as well as optimal utilization of the ASALs under changing climates.

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