Eastern Africa Journal of
Contemporary Research (EAJCR)

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Article information:

To cite this article:

Mwaila M., et al., (2026). *Extreme Heat Exposure and Neonate Death Nexus: Analysis of High Neonatal Mortality Burden Counties in Kenya. Eastern Africa Journal of Contemporary Research, 6*(1), 41-54.

For Authors

About Eastern Africa Journal of Contemporary Research (EAJCR)

The Eastern Africa Journal of Contemporary Research (EAJCR) is both an online (ISSN: 2663-7367) and print (ISSN: 2663-7359) double-blind peer-reviewed quarterly journal published by the Directorate of Research and Publications of Gretsa University, Kenya.

EAJCR aims at advancing the frontiers of knowledge by publishing contemporary multidisciplinary conceptual/ theoretical and empirical research articles as well as case studies and book reviews.

Vol. 6, Issue 1, 2026, ISSN: 2663-7367 (Online) & ISSN: 2663-7359

Extreme Heat Exposure and Neonate Death Nexus: Analysis of High Neonatal Mortality Burden Counties in Kenya

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Abstract

Despite significant gains in infant and under-five survival in Kenya, neonatal mortality has remained largely stagnant over the past two decades. Emerging global evidence shows a strong link between extreme heat exposure and adverse birth outcomes. This study investigated the correlation between extreme heat exposure and neonatal mortality in Kenya's five most-affected counties between 2000 and 2021. ***Research methodology:*** *Using retrospective data from the World Bank Group's climate portal and the UN Inter-Agency Group for Child Mortality Estimation (UN-IGME), the study analyzed trends in annual minimum and maximum surface air temperatures and relative humidity alongside neonatal death rates. Further, the study examined national and county-level mean annual temperature trends from 1963 to 2023.* ***Results:*** *Findings revealed no statistically significant correlation between neonatal mortality and temperature or humidity during the study period. While Kendall's tau correlation showed a weak positive relationship between neonatal mortality and temperature from 2000 to 2007, this shifted to a negative correlation in later years—most pronounced in 2016 and 2021. Similarly, humidity exhibited fluctuating associations, with weak or no consistent correlation to neonatal deaths.* ***Conclusion:*** *The study results point to the urgent need for improved data quality and granularity at the county level to enable more nuanced, long-term analyses as well as use of more advanced data analyses tools. As Kenya continues to experience rising temperatures, further research is critical to unpack the complex pathways linking climate hazards to neonatal health outcomes.*

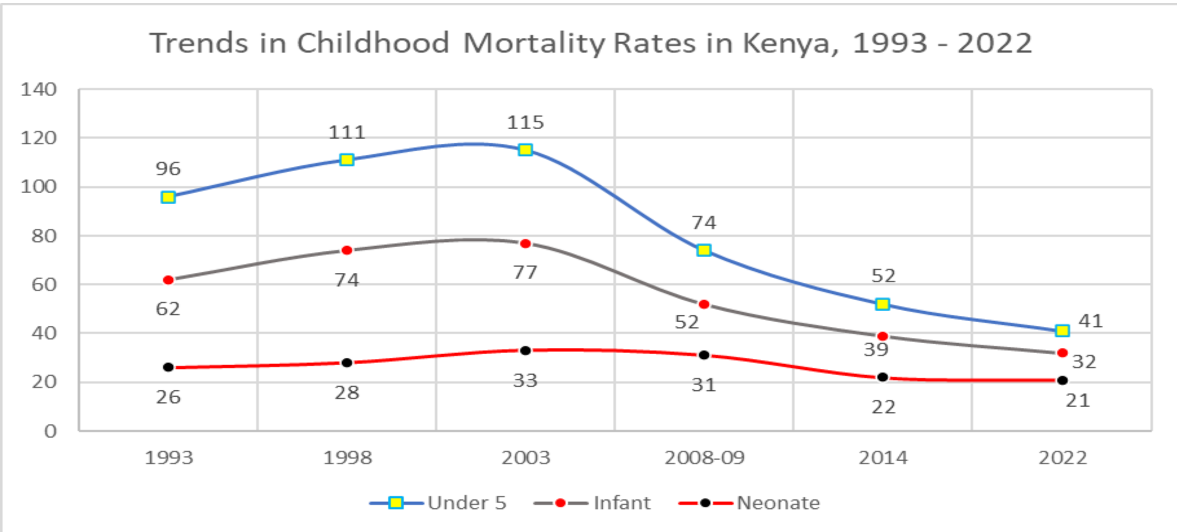
Keys words: *Extreme heat; Neonatal mortality; Pregnancy outcomes; Climate variability; Population, Health and Environment*

1. Introduction

Ocean heat is a crucial measure of climate change considering that mass waters sequester about 90 percent of global heat. A study by Cheng, *et al*. (2025) observed that in 2023-24 the global upper 2000m ocean heat content was approximately 140 times higher than the 2023 global electricity generation. This confirms that 2024 was the warmest in a series of 10-year global temperatures rising to 1.55ºC above the pre-industrial period surface temperature average (WMO, 2025). Populations in low-and-middle income countries (LMICs) are more vulnerable to negative socio-economic impacts of rising temperatures given their low adaptive capacities.

The United Nations Sustainable Development Goal 3 and the World Health Organization's "Every Action Newborn Plan" target to reduce the high burden of neonatal mortality (UN, 2024; WHO, 2014). SDG Target 3.2 calls on countries to reduce neonatal deaths to 12 or lower per 1,000 live births by 2030 (SDSN, n.d.). However, global records estimate about 2.3 million newborn deaths annually (UNICEF, 2024; UN, 2024). Kenya's neonatal death rates have almost stagnated over the last two decades despite significant improvements in infant and under 5 mortality rates in the last decade (KNBS & IFC, 2023). Figure 1 shows trends in childhood deaths - number of deaths per 1,000 live births in the 5-year period prior to demographic and health survey cycles.

Figure 1: Kenya's Childhood Mortality Trends, 1993-2022



Source: KNBS & ICF, 2023

Neonatal mortality refers to deaths occurring in newborns within 28 days after birth. Studies indicate that most of such deaths occur within 24 hours and first week of life. Exposure to high temperatures has been related to pregnancy and birth complications such as pre-term births, low birth weight, malnutrition, respiratory and other infections. In fact, WHO in Meherali, *et al*. (2024) states that children and newborns in low-resource settings bear about 88 percent of climate-related disease burden.

Studies show a correlation between extreme heat exposure and negative birth outcomes

(Meherali, *et al*., 2024; Baharav, *et al*., 2023). A meta-analysis conducted mainly for high income countries noted that heat stress can lead to stillbirths, congenital defects, low birth weight and premature births (Lakhoo, *et al*., 2024). Similar outcomes were observed in a study in Kilifi County, Kenya (Scorgie, *et al*., 2023) and apart from stillbirth, the rest are major causes of death within 28 days after birth.

Global temperatures are rising and extreme heat events are becoming more frequent and intense (Baharav, *et al*., 2023). Africa has been observed to be warming faster than the rest of the world (WMO, 2023). For this reason, it is imperative to assess the impact of heat on pregnancy outcomes and the health of neonates for targeted actions towards attainment of SDG3. In Africa, specifically, average warming rates increased by 50 percent, from 0.2^0 Celsius per decade between 1961 and 1990 to 0.3^0 Celsius per decade between 1991 and 2022 (WMO, 2023). According to the 2022 Kenya Demographic and Health Survey (KDHS), counties with high neonatal mortality burden include: Wajir (37/1000), Kirinyaga (37/1000), Migori (37/1000), Murang'a (36/1000), Baringo (33/1000), Mombasa (32/1000), Homa Bay (32/1000), Kiambu (28/1000) and Garissa (28/1000) (KNBS & ICF, 2023). However, analysis of data from the UN Inter-Agency Group for Child Mortality Estimates (UN-IGME) over a period of slightly over two decades (2000 to 2021), five counties reported the highest average neonatal mortality rates of over 30 per 1000 live births. These are Tana River, Garissa, Nairobi, Nyandarua and Migori and they form the basis of this study.

The UN-IGME neonatal deaths estimates for Kenya observe the leading causes of mortality between 2000 and 2021 as prematurity (7.8/1000); birth asyphxia/trauma (4.3/1000); congenital anomalies had an upward trend (1.57/1000) and lower respiratory infections (1.3/1000) by 2021.

This study sought to assess the relationship between extreme heat exposure and neonatal deaths in five high neonatal mortality burden counties between 2000 and 2021 in Kenya. Specifically, the study determined trends in temperature and humidity in Kenya since independence, i.e. 1963 till 2023, while trends in neonatal mortality cover 2000 and 2021 (UN-IGME, 2025); and assessed the relationship between extreme heat exposure and neonate deaths during the period 2000 to 2021. WMO recommends longer time periods in studying climate trends because of 'natural variability' (WMO, n.d.).

2. Literature Review

Extreme heat increases mortality majorly through interaction with existing health conditions of cardiovascular, cerebrovascular, and respiratory diseases (Ebi, *et al*., 2004). Researchers have identified an association between extreme heat days and an increased risk of neonatal mortality (Relative Risk = 1.53; 95% CI = 1.16 – 2.02) (Basagana, *et al*., 2011). Traditionally marginalized and low-income communities in the United States suffer greater heat-related maternal morbidity and mortality (Kim, *et al*., 2021): a neonate is likely to die following the death of the mother. A study by Hsu, *et al*. (2021) noted that lower socioeconomic status and historically marginalized communities were frequently exposed to higher temperatures which have negative consequences on human health and well-being (Baharav, *et al*., 2023).

Studies show that high temperatures alter hormonal and immune systems to generate changes in the placenta (Bonell *et al*., 2023). Such changes increase the risks of hypertensive disorders and placental abruption (Dalugoda, *et al*., 2022; Shashar, *et al*., 2020; Part, *et al*., 2022; He, *et al*., 2018; Rammah, 2019), and triggers contractions (Samuels, 2022; Bonell, *et al*., 2020) that directly affect fetus survival (Hason, *et al*., 2024). Heat leads to epigenetic changes and altered imprinting resulting in birth defects (Haghighi, *et al*., 2021) that are risk factors for neonatal deaths (Aminu, *et al*., 2014). Overwhelmed thermoregulation reduces central blood flow leading to placental hyperpoflusion, dehydration, hypovolemia and other physiological effects (Bonell *et al*., 2020; Wells, 2002). This reduces placental capacity and introduces oxidative stress that triggers preterm birth (Chersich, *et al*., 2020; Dalugoda, *et al*., 2022; de Bont, *et al*., 2022), which is a neonatal mortality risk (Nakstad, *et al*., 2022).

In Canada, maximum weekly temperature of 30^0 Celsius compared to maximum weekly temperature of 15^0 Celsius was found to be associated with increased risk of pregnancy abruption (OR = 1.12; 95% CI = 1.02 – 1.24) (He, *et al*., 2018). The researchers noted that the association was more pronounced in women characterized by: being nulliparous, under 35 years of age, and of low socioeconomic status. In terms of access to healthcare, Kim, *et al*., (2021) found increased risk of hospitalization as a result of antepartum haemorrhage with exposure to extreme heat. Antepartum haemorrhage is one of the leading causes of maternal mortality and, by extension, neonatal mortality.

Research indicates that heat exposure increases the likelihood of dehydration and the secretion of antidiuretic hormones and oxytocin, contributing to preterm births (Samuels *et al*., 2022; McElroy, *et al*., 2022; Ilango, *et al*., 2020), yet preterm birth is a leading cause of neonatal mortality (Strand, *et al*., 2011; Zhang, *et al*., 2017; Son, *et al*., 2019). In the United States, Ha, *et al*., (2017) found heat exposure correlated with a 6 percent to 21 percent increase in the risk of preterm birth at weeks 34 to 38 of pregnancy. On their side, Chersich, *et al*. (2020) found that the likelihood of preterm birth rose 1.05 times with every single degree Celsius increase in temperature (OR = 1.05; 95% CI = 1.03 – 1.07) (2020). Heat wave conditions further increased the odds of preterm birth by 1.16 times. In Seoul, South Korea, mothers with low education level and who lived in communities of low socioeconomic status suffered the most significant and strongest effect of heat on preterm birth (Son, *et al*., 2019).

High income countries have grounded research on heat exposure compared to low-income countries which are still grappling with information and financial resources to increase adaptive capacity. A study by Kunda, *et al*. (2024), reviewed over 5,000 studies of which only 100 were from tropical Africa and discussed heat exposure. For Kenya, there were only nine studies and two were multi-country where Kenya was part of. Ibid's research on effects of extreme heat on health observed rising temperatures in tropical Africa especially since 1980s leading to adverse health impacts. The study revealed a number of health impacts due to extreme heat exposure noting cases of stillbirths, miscarriages and under five mortalities. In Kenya, approximately 436 under-five deaths were reported within two years (2003 - 2005) when temperature was recorded at 34ºC (Mutisya, *et al*., 2010). The review also pointed to cases of heatwaves in tropical Africa affecting both urban and rural settings. Data from UN-IGME confirms that Kenya experienced a high neonatal mortality (7.8/1000) due to prematurity during the study period.

3. Methodology

This study was based on five high neonatal mortality burden counties of Garissa, Migori, Nyandarua, Tana River and Nairobi as per the United Nations Inter-Agency Group for Child Mortality Estimation (UN-IGME) data. It was a retrospective study using data from the World Bank Group climate data portal and the UN-IGME. The data tracked annual mean temperature and relative humidity since Kenya's independence in 1963 to 2023. For comparability, minimum/maximum temperature and neonatal mortalities in the five high burden counties were computed for the period 2000 to 2021 to provide a more current status.

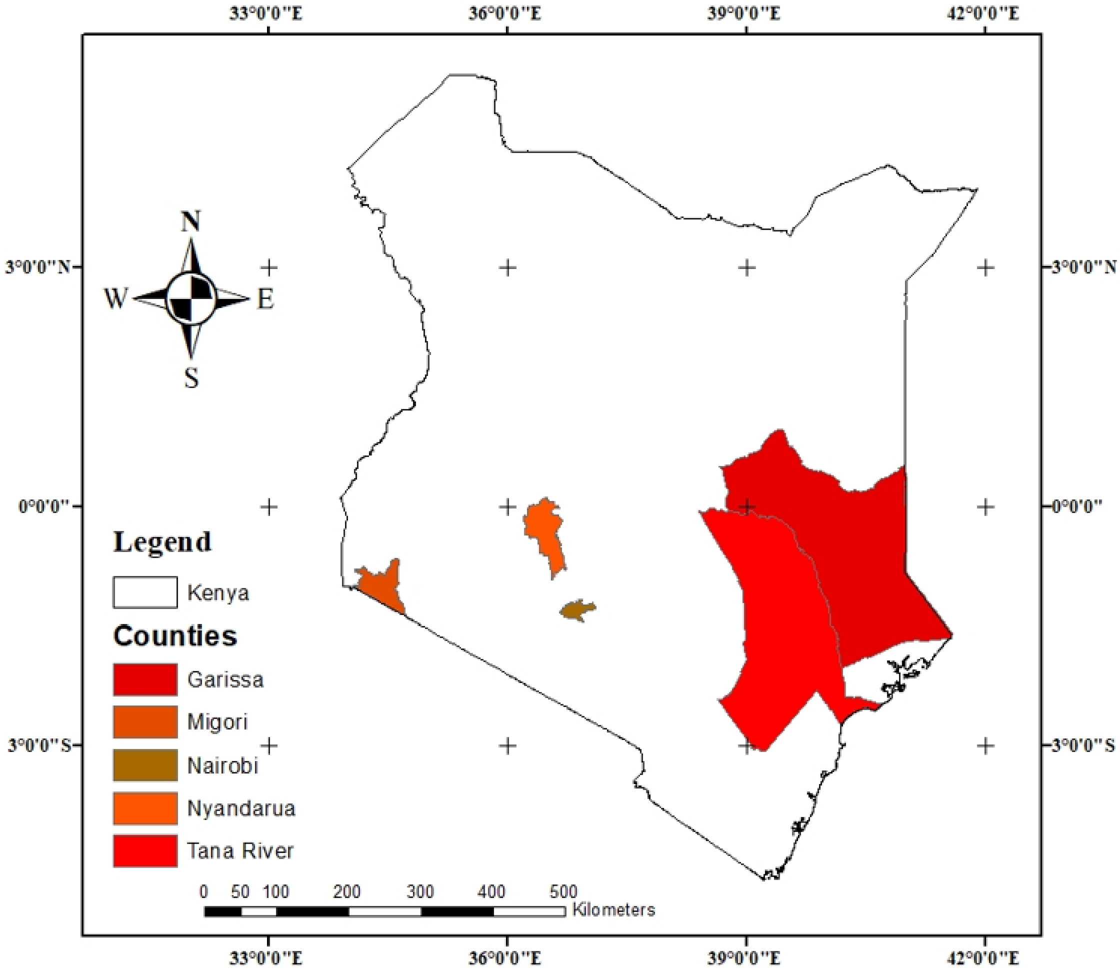
The quantitative study deployed descriptive and inferential techniques in SPSS version 25. Descriptive statistics were used to provide information about the study area and neonatal deaths while inferential statistics engaged Pearson's and Kendall's Tau correlations to test existing relationships and their significance. A humidex was constructed to visualize the extent of heat exposure in the five counties.

4. Findings and Discussion

4.1 Geographical Locations of High Neonatal Burden Counties

Figure 2 shows the geographical locations of the five Counties. Nairobi is the largest/capital city in south-central part of Kenya whose population is 100% urban. Laying on the eastern part of the great rift valley, Nairobi has a temperate climate and borders Kiambu, Machakos and Kajiado. Garissa is among 23 counties within the arid and semiarid zone. Garissa has a flat terrain. The county borders Tana River, Isiolo, Wajir and Lamu counties and Somalia to the East. Migori County is located in the southwestern part of Kenya. The county enjoys tropical climate conditions and fertile soils. Migori borders Tanzania and Lake Victoria to the west, at Homa Bay, Kisii and Narok. Nyandarua County is located on the western slopes of the Aberdare ranges. The county boasts of high agricultural productivity and a high forest cover. The population is mainly rural. Nyandarua County borders Laikipia, Nakuru, Kiambu and Nyeri. Just like Garissa County, Tana River County is a semi-arid county with mixed features of a riverine and delta ecosystems thus prone to flooding. The county borders Garissa, Lamu, Kitui, and Kilifi Counties (County Integrated Development Plans (CIDPs), 2023).

Figure 2: Geographical Location of 5 Counties with High Neonatal Mortality Burden

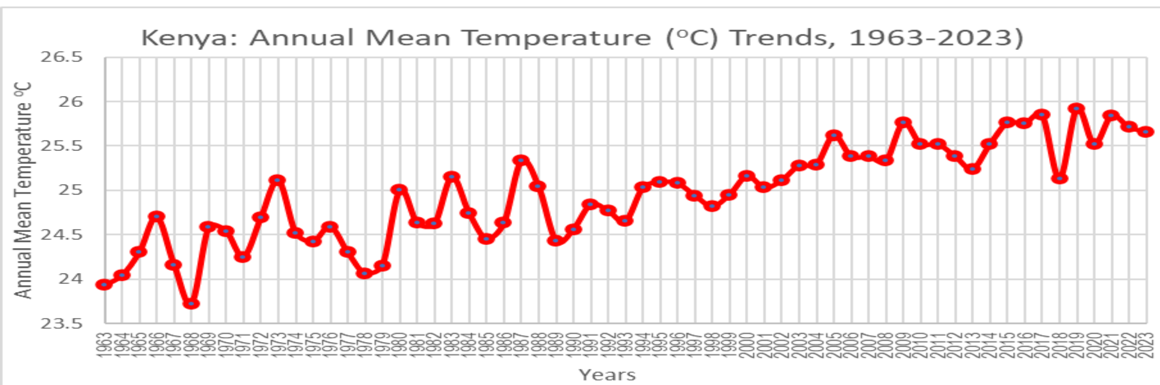


Source: Generated using ArcGIS V10.8, 2025

4.2 Kenya's Temperature and Humidity Trends, 1963-2023

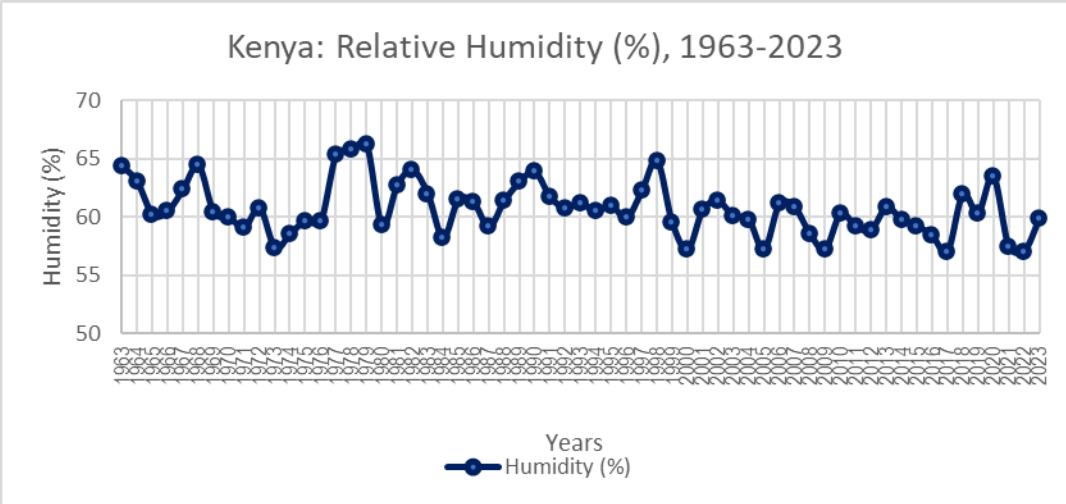
Figure 3 indicates a rising trend in annual mean temperature over the last 60 years. The general outlook depicts an increase of 1.73ºC in mean temperature between 1963 and 2023. Kenya, like the rest of Africa is warming. Figure 4 shows trends in relative humidity over the same period. In 1979 Kenya experienced the highest humidity of 66.28 percent.

Figure 3: Annual Mean Temperature in Kenya, 1963-2023



Source: Curated from World Bank Climate Knowledge Portal accessed on 02.06.2025

Figure 4: Annual Humidity in Kenya, 1963-2023

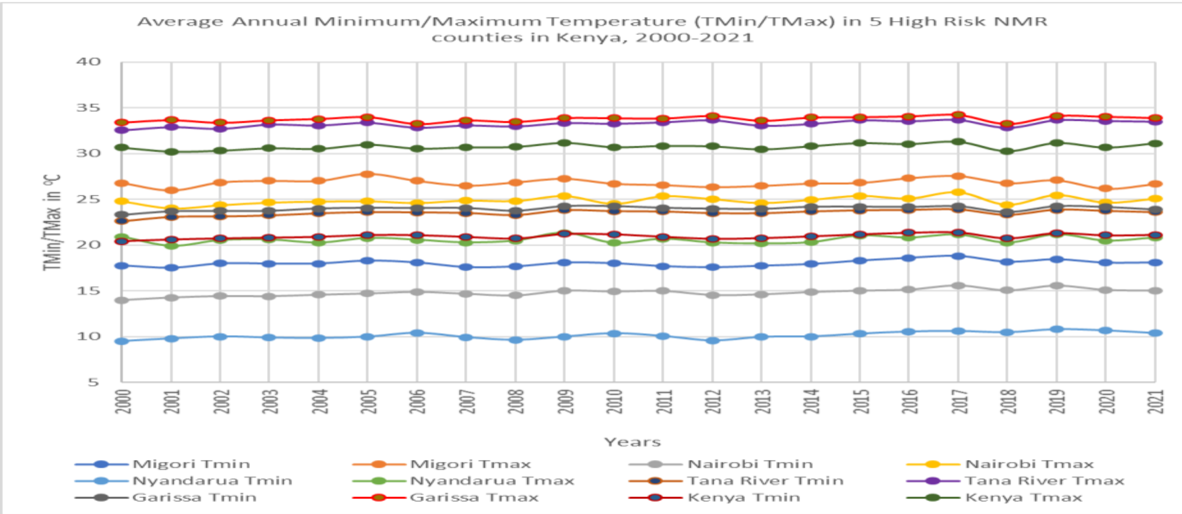


Source: Curated from World Bank Climate Knowledge Portal accessed on 02.06.2025

4.3 Trends in Average Annual Minimum/Maximum Temperature in High Neonatal Mortality Counties, 2000 - 2021

In the decadal reporting of 2013-2022, global surface temperature was recorded at 1.14°C above the pre-industrial period of 1850–1900 (WMO, 2022). Increased frequency of extreme weather events such as storms, floods, droughts, extreme temperature and wildfires have been reported since 1970 (World Bank Group, 2023). In Kenya, the lowest average annual minimum temperatures were reported in Migori (18.02ºC), Nairobi (14.82ºC) and Nyandarua (10.13ºC) all below the national average (20.96ºC) while Garissa (23.98ºC) and Tana River (23.52ºC) had the highest average annual minimum temperatures. The two also recorded the highest annual average maximum temperatures of 33.76ºC and 33.23ºC in Garissa and Tana River as presented in Figure 5.

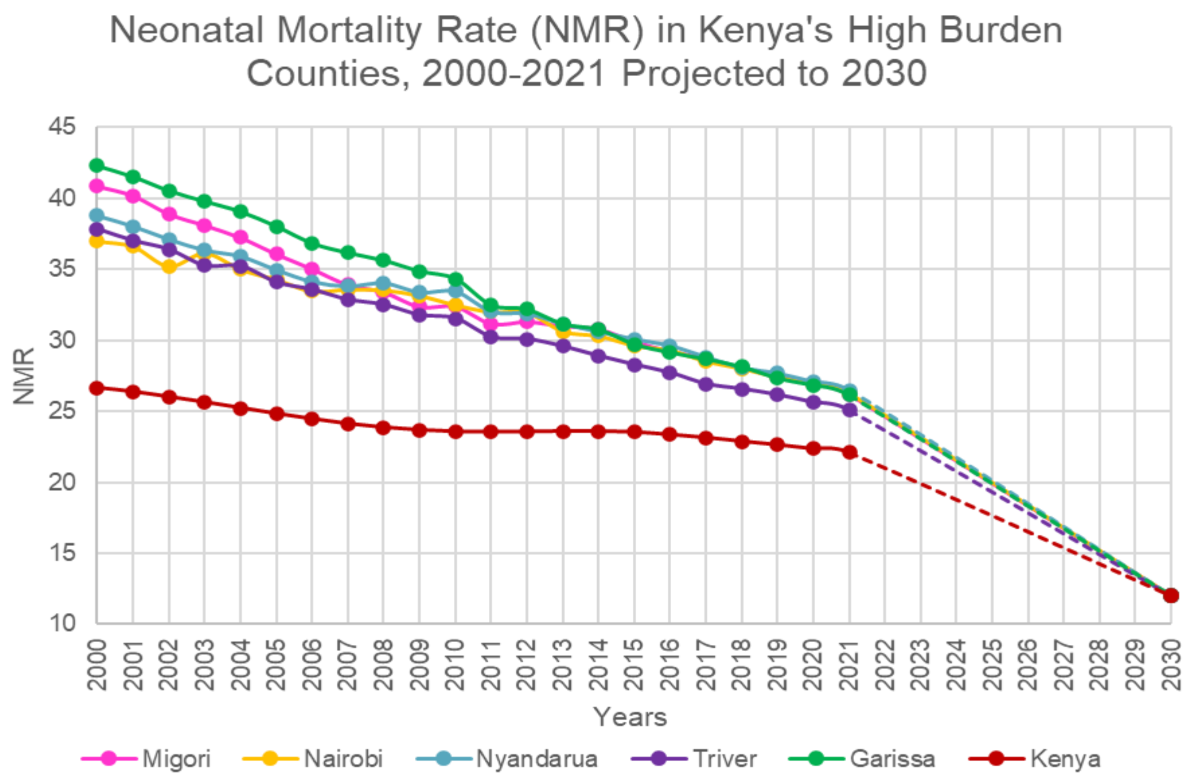
Figure 5: Trends in TMin/TMax and NMR in High Burden Counties, 2000-2021



Source: Curated from World Bank Climate Knowledge Portal accessed on 03.06.2025

Despite showing a gradual downward trend over the two decades (2000-2021), neonatal mortality rates remain high with averages of 33.7/1000 live births in Garissa, 32.7/1000 in Migori, 32.4/1000 in Nyandarua, 31.9/1000 in Nairobi and 31.1/1000 in Tana River Counties compared to the national average of 24/1000 over the same period. Figure 6 presents the trends.

Figure 6: Trends in Neonatal Mortality Rates in Kenya, 2000 – 2021 Projected to 2030



Source: Curated from UN-IGME accessed on 02.06.2025

4.4 Correlation between Neonatal Mortality and TMin/TMax and Humidity

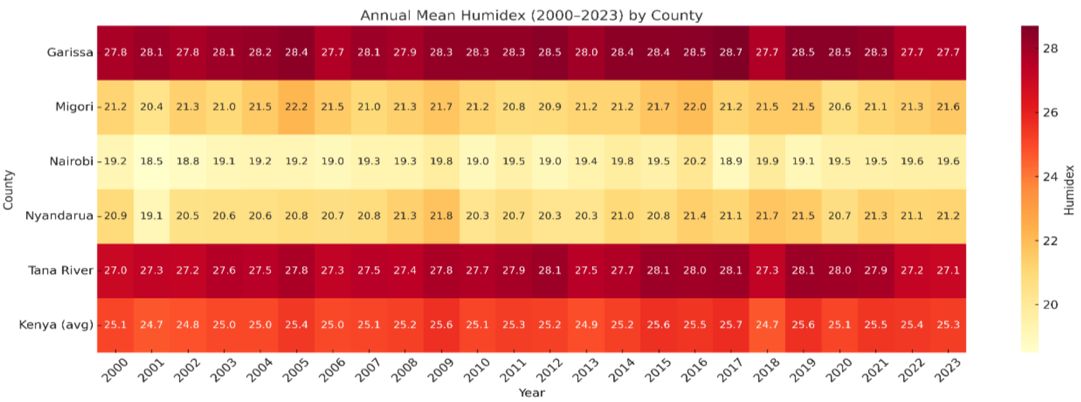
Pearson's correlation observed a negative relationship between neonatal mortality and annual minimum/maximum average temperature (TMin/TMax) during the study period. Neonatal mortality was negatively related to humidex throughout the study period (2000-2022). Meantime, in Kendall Tau-b correlation, there was a weak positive association between neonatal mortality and humidex between 2000 and 2007. The relationship turned inverse from 2008 onwards. The strength was weak to moderate up to 2007 (38.5%) but grew to above 60 percent in some years. From 2000 to 2007, Kendall's Tau correlation noted a weak positive to moderate relationship between neonatal mortality and humidex (6.7-46.7%), thereafter the relationship was negative and strongest in 2016 and 2021 (60%). A positive association means as humidex increases, neonatal mortality increases and the reverse is the case when the coefficients are negative. Both Pearson's and Kendall's Tau correlations showed no statistically significant relationship between neonatal mortality and humidex in the five counties.

4.5 Heat Exposure Index (Humidex) of the Five High Neonatal Mortality Counties

To measure heat exposure in the five high neonatal mortality counties, the study used the Humidex – a useful tool for assessing perceived heat used in Canada and the Commonwealth Countries. The model is useful in community and heat impact studies.

Garissa and Tana River are zoned as Arid and Semi-Arid (ASALs) Counties. In this study, the two recorded the highest heat exposure index over the study period as illustrated in Figure 7. In Nairobi, humidex has been consistently above 19ºC since 2003 which could be explained from the effects of urban heat island. All the study counties fall within the <29ºC threshold of 'Bearable'. However, these thresholds are not necessarily universal and are probably applicable to adults and not neonates. Lack of county aggregated child mortality data due to low reporting of neonatal deaths and instances of mixing stillbirths and neonatal deaths could be the 'blind-spot' resulting in lack of a statistically significant correlation between neonate death and humidity.

Figure 7: Humidex Trends in the Five Neonatal Mortality Burdened Counties, 2000-2003



Source: Generated using Advanced Excel tools

Table 2: Heat Index (°C) Impact Level

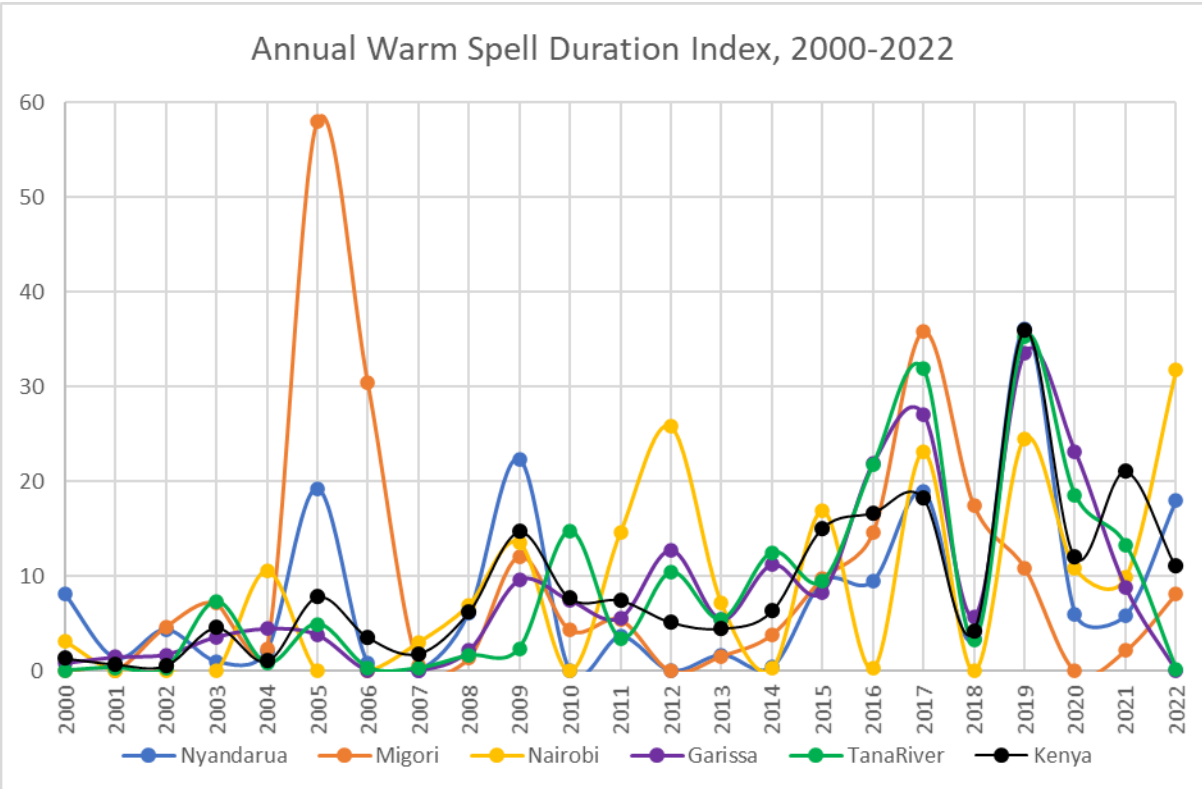
Threshold (°C)	Impact Level	Health Impact
<29	Bearable	No health risk
30 - 39	Caution	Sweating/Fatigue
40 - 45	Extreme caution	Exhaustion/ heat cramps risk
46 - 54	Danger	Heat cramps/ heat stroke risk
54+	Extreme danger	Heat stroke

Source: Lawrence (2005)

4.6 Warm Spell Duration Index

The study considered another parameter – the Warm Spell Duration Index (WSDI) and its association with neonate deaths. The index measures the number of days when TMax exceeds thresholds usually above 90th percentile of a 5-day moving baseline for at least six consecutive days annually. WSDI is useful in tracking heatwave magnitude and frequency. Figure 8 shows the WSDI for the five counties.

Figure 8: WSDI in the Five Counties with High Neonatal Mortality Rates



Source: Compiled using data from WBG-CKP (2025) accessed on 05.07.2025

In Pearson's correlation, neonatal mortality rate of 2000 to 2021 and warm spell duration index of 2021 showed significant ($p<0.05$ at 95% CI) and very strong (>80%) inverse relationship except for neonatal mortality rate of 2009 where WSDI was not significant. However, neonate deaths from 2000 to 2021 were positively associated with warm spell duration in 2000-2002; 2004-2006; 2012; 2017-2018.

For Kendall's tau-b, neonatal mortality rate from 2000 to 2021 was correlated with WSDI for the same period. As observed in Table 3, significant correlation was noted where p<0.05 and strong inverse association between neonatal mortality and warm spells duration with coefficient of -0.733 and -0.867.

Table 3: Kendall's tau-b Correlation with Neonatal Mortality Rate, 2000 to 2021

NMR	WSDI	Coefficient	p-value
2003	2021	-0.733	0.039
2005	2021	-0.733	0.039
2007	2021	-0.733	0.039
2013	2021	-0.733	0.039
2014	2021	-0.867	0.015
2015	2021	-0.867	0.015
2016	2010	-0.733	0.039
2017	2021	-0.867	0.015
2019	2021	-0.733	0.039
2020	2021	-0.733	0.039
2021	2010	-0.733	0.039

Source: Computed by Authors

Kendall's tau-b observed significant positive correlation between neonate deaths from 2000 to 2021 and warm spell duration indices of 2002, 2004, 2017-2018.

5. Conclusion and Recommendations

5.1 Conclusions

Although neonatal mortality has been falling in the five high burden counties over the last two decades, the pace is not fast enough for the attainment of SDG3 Target 3.2 which calls on community of nations to reduce neonatal mortality to at 12 deaths or lower per 1,000 live births by 2030. The study could not conclusively establish strong association between temperature and neonatal death due to variations from weak to strong or positive to negative associations. However, in most instances, humidity was positively associated with neonatal deaths. Both Pearson's and Kendall's tau-b correlations found a significant strong inverse relationship between neonatal mortality and most instances of warm spell duration index in 2021 in the five counties.

5.2 Recommendations

Research on effects of climate variability on neonatal and child health in Kenya remains scarce. As Africa's warming accelerates, investment in quantitative studies is required to support the generation of mortality data for evidence-based SDG3 tracking and reporting as well as for policy development. Qualitative studies are equally critical for enhancing contextual understanding.

Kenya needs to make deliberate efforts in the implementation of population health – a holistic approach to health and wellbeing within the life course especially towards promoting maternal and child health. Population Health and Environment is a deliberate investment that uses a people-centred approach where strategic investments are made in epidemiological mapping of communities and a database of diseases generated. Technology is applied to provide the much-needed healthcare to the last mile. Meantime, communities are encouraged to maintain healthy lifestyles by ensuring good nutrition, maintaining clean environments and good sanitation and sustaining health seeking behaviour.

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