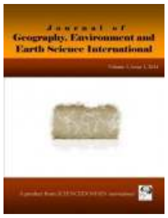

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Investigation of Heat Wave Characteristics Over Selected Stations in Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

In this study, the excess heat factor (EHF) index was applied in five (5) selected stations in Nigeria to investigate heat wave characteristics. The EHF originally introduced for use in Australian heatwave monitoring and forecasting, has now been incorporated into a newly designed climpact R-based package used in this work. This work had analysed over 30 years of daily precipitation, minimum and maximum temperature data, as the climate base period, for the selected stations: guinea savannah: Lokoja, Minna; sudan savannah: Kano; sahel: Sokoto, Maiduguri. Daily input data were checked for quality and homogeneity by the climpact software, which also computed and plotted the indices.

Sokoto, Kano, and Minna had the highest heat wave number of six (6), nine (9), and seven (7) respectively in 1987, Maiduguri had highest heat wave number of seven (7) in 1983 while Lokoja had highest heat wave number of five (5) and four (4) in 2005 and 1987 respectively. The lengthiest and shortest heat wave duration (HWD) was identified in 1983 and 1997 respectively for Sokoto, in 1991 and 2005 respectively for Maiduguri, while Kano and Lokoja had the same pattern of heat wave duration over the years. Maiduguri had higher heat wave frequencies than other stations.

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Sokoto and Maiduguri had close to severe conditions based on their magnitude levels for both the heat wave amplitude and mean magnitude. Whereas, in Kano there was an almost constant heat wave amplitude and mean magnitude condition over the years. In Minna, opposite conditions as against Maiduguri were identified.
Generally, all results indicated moderate conditions, since severe or even extreme cases rarely occurred. This implied that the southern Sahel and the savannah stations investigated in this study have not been highly affected by heat wave conditions but at some moderate levels over the years under investigation.

Keywords: Excess heat factor; heat wave; climate base period.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change, [1], suggested that the warming of the climate system is unequivocal, based on observational data. The IPCC report highlighted that anthropogenic influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century, and has more than doubled the probability of occurrence of heat waves in some locations. Similar findings regarding the increased risk of heat extremes due to anthropogenic activities are presented in a number of studies, [2,3,4]. In the likely scenario of a 2℃ warmer world, almost every future summer will be as hot as or hotter than the hottest that people have experienced in the recent past [5].

Heat waves are generally referred to as a period of excessively high temperatures or hot weather events. Extreme events typically occur in mid-summer. There is no single definition of heat wave, quantitative definitions of heat waves differ in:

1. The metric of heat used, e.g., daily mean temperature (Tmin), [6], daily Tmax, [7] and [8], temperature and humidity, [9] and [10], and apparent temperature, [11];
2. The manner in which thresholds of exceedence are defined – as an absolute threshold (e.g., Tmax greater than 40.6 ℃, [12]), or as a relative threshold, (e.g., the 95th percentile, [6]); and/or
3. The role of duration in a heat wave definition (e.g., 1 day, [13], or multiple length criteria, [8].

[14] made a distinction between heat waves, as periods which are hot in an absolute sense, and warm spells, as periods which are hot in a relative sense. Warm spells, according to [14] may occur at any time of the year, even in the middle of winter, whereas heat waves are necessarily restricted to the summer part of the year. In climatic terms, they considered heat waves to be associated with unusually high temperatures, whereas a warm spell is considered to be associated with unusually high temperature anomalies. Both concepts (heat waves and warm spells) are intrinsically meaningful, but they are clearly not the same thing.

Several other definitions of heat waves have been proposed previously for use. One by [15] requires that the maximum temperature be above the 90th percentile for three consecutive days, with the minimum temperature being also above the 90th percentile for the second and third days. If the 90th percentile thresholds are calculated with respect to the entire year, then heat waves will be diagnosed, whereas if the percentile thresholds are relative to the calendar month or season, then warm spells will be diagnosed. In the former case, the heat waves diagnosed by the [15] method will have much in common with the heat waves diagnosed by the EHF method proposed by [14]. In the latter case, the warm spells diagnosed will have much in common with our heat waves in the summer months, but less so during the rest of the year. [16] have compared a wide range of warm spell and heat wave indices, noting the utility of differing indices dependent upon their intended use. In this regard, warm spell indices are useful and provide information relevant to seasonally dependant temperature requirements for agriculture especially in West Africa where the economy is rain fall dependant, whilst heatwave indices are relevant to adaptation measures when dealing with temperature extremes [14].

The diversity of definitions reflects the diversity of reasons that heat waves are studied. Climate scientists, who are primarily interested in the evolving statistics of weather in climate change, tend towards definitions that include a probability of exceedance in some relatively straightforward metric, usually defined relative to a long term mean (e.g., [17] and [18]). Health researchers, in contrast, are interested in the aspects of a heat wave that are most relevant to human well-being.

Despite that heat waves sometimes occur without significant consequences, their effects may be more widespread than other severe weather phenomena or natural disasters [19].

2. DATA AND METHODOLOGY

Monthly averages of climate data smooth over a lot of important information that is relevant for sectoral impacts. For this reason indices derived from daily data are an attempt to objectively extract information from daily weather observations that answers questions concerning aspects of the climate system that affect many human and natural systems with particular emphasis on extremes. Such indices might reflect the duration or amplitude of heat waves, extreme rainfall intensity and frequency or measures of extremely wet or dry/hot or cold periods that have socio-economic impacts. Climate indices provide valuable information contained in daily data, without the need to transmit the daily data itself.

For this reasons, this work had analysed over 30 years of daily precipitation, minimum and maximum temperature data, as the climate base period, for some selected stations (GUINEA SAVANNAH: Lokoja, Minna, SUDAN SAVANNAH: Kano, SAHEL: Sokoto, Maiduguri), as shown in Fig. 1. These data were collected from the Nigerian Meteorological Agency (NIMET).

The following concepts are developed in order to provide a platform for developing a heatwave definition that is applicable to any location. Indices are adopted that match these concepts as detailed by [20].

2.1 Excess Heat

This is unusually high heat arising from a high daytime temperature that is not sufficiently discharged overnight due to unusually high overnight temperature.

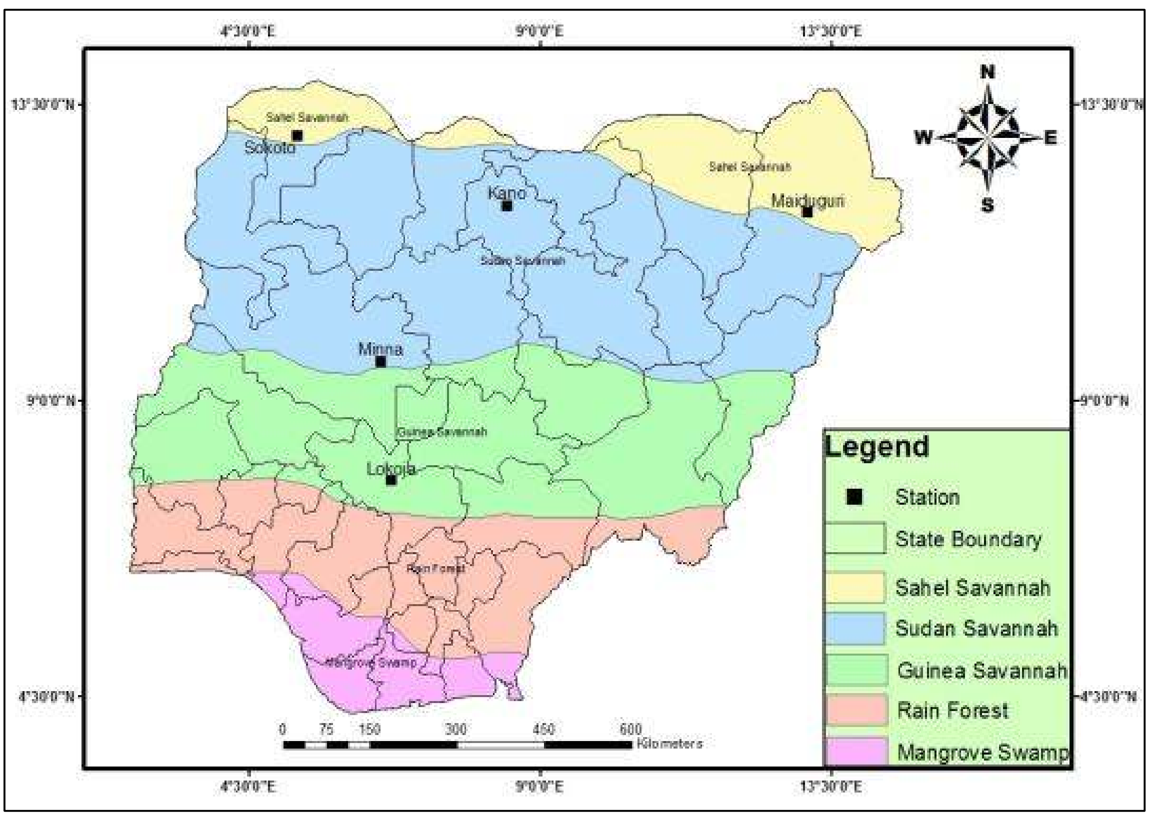


Fig. 1. The map of Nigeria showing study stations in the climatic zone

Maximum and subsequent minimum temperatures averaged over a three-day period are compared against a climate reference value to characterize this unusually high heat in an excess heat index. This is expressed as a long-term (climate-scale) temperature anomaly.

The long-term climate reference value for determining the existence of a significant excess heat event has been set as the 95th percentile of observed daily temperature (single-day, average of maximum and minimum temperature in a common 9 am to 9 am period) for all days spanning the climate base period of analysis. Positive contiguous three-day-average daily temperature departures from this reference value indicate a significant excess heat event or heatwave. This motivates the form of our first excess heat index [21],

$$EHI_{sig}=(T_i+T_{i-1}+T_{i-2})/3.-T_{95} \quad (1)$$

Where T_{95} is the 95th percentile of daily temperature (T_i) for the climate base (reference) period, calculated using all days of the year. As previously mentioned, daily mean temperature (DMT) is defined as

$$T = (T\text{max} + T\text{min})/2, \quad (2)$$

across the 24-hour period, where the maximum temperature typically precedes the minimum temperature in the 9 am to 9 am (local time) observation period. The DMT *Ti* on day *i* is in ℃. The units of *EHIsig* are also ℃. By construction, *EHIsig* is in effect an anomaly of three-day DMT with respect to climatological 95th percentile of the DMT.

2.2 Heat Stress

This arises from a period where temperature is warmer, on average, than the recent past. Maximum and subsequent minimum temperatures averaged over a three-day period and the previous 30 days are compared to characterize this heat stress in a second index. This is expressed as a short term (acclimatisation) temperature anomaly. Acclimatisation to higher temperatures is a feature of human physical adaptation which may take between two to six weeks, involving physiological adjustments of the cardiovascular, endocrine and renal systems ([22] and [23]). In this work, 30 days (about 4 weeks) has been used as the period required for acclimatisation. This motivated [21] to define a second excess heat index,

$$EHI_{accl}=(T_i+T_{i-1}+T_{i-2})/3-(T_{i-3}\}+...+T_{i-32})/30 \quad (3)$$

where T_i is the DMT on day *i* defined in the previous section. In effect, *EHIaccl* is an anomaly of three day DMT with respect to the previous 30 days. The units of *EHIaccl* are ℃. This index can be applied to both biological and engineered systems. Heat regulation in biological systems requires an adaptive response by a range of interacting organs.

2.3 Excess Heat Factor

The combined effect of Excess Heat and Heat Stress calculated as an index provides a comparative measure of intensity, load, duration and spatial distribution of a heatwave event. Heatwave conditions exist when the EHF is positive. Combining the measures of Excess Heat and Heat Stress provides a measure of heatwave which has a strong signal-to-noise ratio. Low-impact heat waves register as low-amplitude EHF events. As the Excess Heat and Heat Stress temperature anomalies increase, their product increases as a quadratic response to increasing heat load. Multiplying these two indices (instead of adding them) has been favoured because a similar quadratic signal is detected in high impact data. Quadratic responses to extreme heat events are noted for mortality, ambulance response and power consumption [24]. [21] defined the excess heat factor as

$$EHF=EHI_{sig}*\max(1,EHI_{accl}) \quad (4)$$

The units of *EHF* are ℃^{2}.

These equation differs slightly from [20], in that the three-day DMT is sampled for the current and following two days (i.e., days *i*, *i*+1 and *i*+2), instead of the retrospective view (i.e., days *i*, *i*–1 and *i*–2). This slight change is motivated by the intention to apply these ideas in the context of a weather forecasting service looking forward in time, but the indices are of course easily calculated using historical data in a retrospective sense.

The definition of *EHF* as presented here has also undergone a subtle reformulation. In the original formula, which had $EHF = EHIsig \times | EHIaccl |$, the factor $| EHIaccl |$ sat in place of the factor max(1,*EHIaccl*) now present in equation (4). The change to the new definition of the *EHF* was motivated by a consideration of what happens in heat waves of long duration. For heat waves which are short relative to the 30-day acclimatisation period, the two definitions are effectively equivalent in terms of their positive values, because *EHIaccl* stays positive for the duration of the event. [Negative values of *EHF* are obviously different in the two formulae, but are excluded from consideration because they denote the absence of a heatwave; this aspect of the change is of little importance.] For long heat waves, particularly as the event is winding down, *EHIaccl* may go negative before *EHIsig*, an undesirable outcome in the original definition of *EHF* which the new definition corrects. [Specifically, they don't want *EHF* to be high when the three-day period is substantially milder than the previous 30 days.]

In summary, *EHF* is positive (meaning that a heatwave is in progress) when *EHIsig* is positive (because the three-day period is hot in an absolute sense, being above the 95th percentile for DMT), but additionally *EHF* is large when the three-day period is substantially warmer than the preceding 30 days (*EHIaccl* >> 1℃). The Excess Heat Factor is quantified by the magnitude of *EHF*, the combined index measure of long and short term temperature anomalies. Unless otherwise stated, the three-day periods represented by values of *EHIsig*, *EHIaccl* and *EHF* will be denoted by the first day of the three-day period.

In the case of a heatwave extending over more than one three-day period, [21] defined the *heat load* of the event as the sum of the consecutive positive *EHF* values. This definition has the benefit of simplicity, but it comes at the slight cost of down-weighting the DMT contributions from the first and last days of the multi-day ($n > 3$) period.

3. RESULTS AND DISCUSSION

3.1 Heat Wave Number Using Excess Heat Factor Methodology

Excess heat factor (EHF) is the combined effect of excess heat and excess stress calculated as an index and it provides a comparative measure of intensity, load, duration, and heat wave events (number). According to [21], Heat wave conditions exist when the EHF is positive.

The heat wave number represents the total number of heat waves in a year. Fig. 2 showed that heat wave number in Sokoto fluctuates on annual basis but as shown by the trend line, it changes between 0 and 1 on the average. This showed that, in Sokoto, the number of heat wave events recorded in a year is either zero (0) or one (1) but may be more than that occasionally. This is seen by the "scatter plot with straight lines and markers" in the graph, in which 1973, 1982, and 1990 recorded three cases each of heat wave number, also in 1987, six (6) events of heat wave was recorded, which is the highest number of heat wave recorded for Sokoto. Most other events are between 0 and 2 with zero (0) cases having the highest number, especially consecutively from 1975 through 1981, 1991 – 1994, and 2000 – 2002.

There is a similar situation in Maiduguri, as observed in Sokoto. In each of 1973 and 1984, as shown in Fig. 3, the number of occurrence of heat waves is four (4), whereas, in 1983, seven (7) different cases of heat wave events were identified or measured by the excess heat factor which happened to be the highest events (number) of heat waves in Maiduguri. Three (3) cases each were identified in 1991 and 2002 while two (2) cases each were identified in 1987, 1990, and 1998. Most years in Maiduguri featured consecutive zero or no heat wave events. This include 1970 – 1972, 1974 – 1976, 1978 – 1981, 1988 – 1989, 1992 – 1997, and 1999 – 2001. Because of the frequent and consecutive zero cases of heat waves, this implies why the trend line slopes between zero (0) and one (1).

Between 1960 and 1980 in Kano, as shown in Fig. 4, most cases of heat waves were zero (0) in each year, except in 1973 where four (4) cases of heat waves were identified in that year. The highest number of cases of heat waves in Kano was in 1987, where nine (9) heat wave events occurred only in that year. Other cases include; six (6) in 2002, and four (4) each in 1973 and 1984.

In Minna, as shown in Fig. 5, cases of heat wave number also had a similar trend as in Sokoto, Maiduguri, and Kano. Trend line remained around zero (0) between 1970 and 1986 with three (3) years of exceptions (two different years in which numbers of cases of heat wave events are one (1) each and in 1983 where the number of cases is two (2) for that year). In 1987, Minna recorded seven (7) different cases of heat waves which is the highest number in record, followed by the event of 2009 in which five (5) cases were identified. Other cases vary between one (1) and two (2) for the years involved.

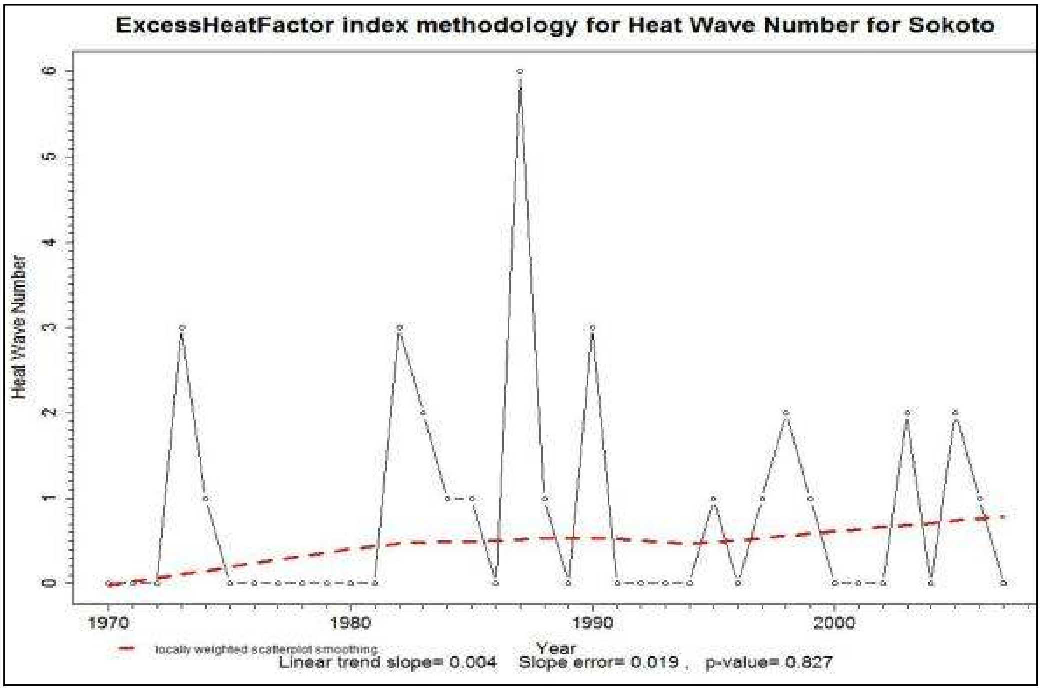


Fig. 2. Showing heat wave number in Sokoto as measured by excess heat factor

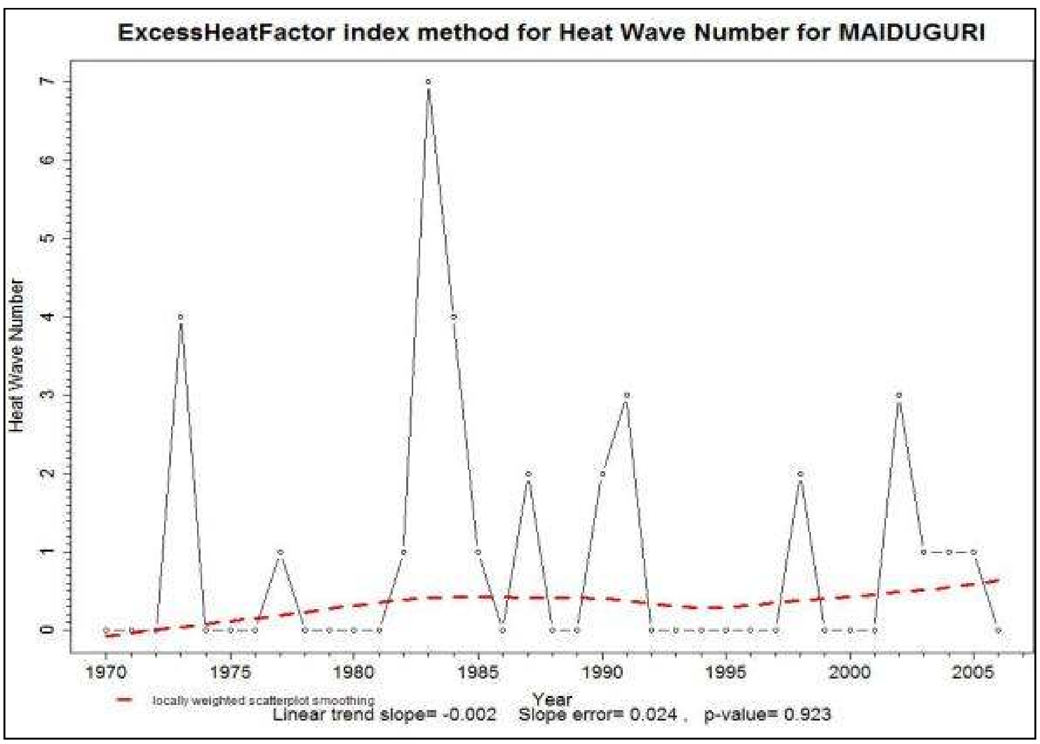


Fig. 3. Showing heat wave number in Maiduguri as measured by excess heat factor

In Lokoja, as shown in Fig. 6, 1980, 1998, and 2002 recorded three (3) heat wave events each. In 1987, four (4) cases of heat waves was identified whereas the highest number of heat wave events was recorded in 2005 with five (5) cases identified in Lokoja. Just like other previous stations discussed, most cases ranges between zero (0) and one (1) in Lokoja.

3.2 Heat Wave Duration Using Excess Heat Factor Methodology

The Heat Wave Duration (HWD) is the average length of all heat waves per year. For example, if five (5) cases of heat waves occurred, say 1940, and the first lasted 7days, the second lasted 9days, the third lasted 8days, the fourth lasted 4days, and the fifth lasted 7days. The heat wave duration is the average of all the heat wave event length, that is, (7+9+8+4+7)/5. Thus, for that hypothetical year, the heat wave duration is 7 days.

Fig. 7 presented the output for Sokoto heat wave duration. The pattern indicated that annual heat wave duration increases initially from above four (4) days in 1973, reached the peak value in 1983 and begin to decrease until 1998. Thereafter, the plot showed tendency that heat wave duration will rise till date. The plot above for Sokoto, indicated that 1983 had the lengthiest or longest heat wave duration during the climate base period under investigation whereas, on the contrary, 1997 recorded the shortest heat wave duration in Sokoto.

In Maiduguri, as shown in Fig. 8, the scenario for heat wave duration indicated falling and rising on decadal basis, from 1973 to 1982, heat wave duration per year fell from above 6days to above 5days, difference of one (1) day. Thereafter, it rises to close to seven (7) days from 1982 to 1991. There was a sharp decrease in heat wave duration from 1991 till 2005 (the end year of the climate data used), from close to seven (7) days to around three (3) days. The result clearly showed that 1991 had the lengthiest heat wave duration in Maiduguri whereas, on the contrary, somewhere after 2005 Maiduguri recorded the shortest heat wave duration.

In Kano, shown in Fig. 9, heat wave duration remained almost constant from 1970 to 1993 with little fluctuations around five (5) days. Thereafter it begins to rise till the end year of the climate base period. This implied that Kano, since 1993, had been experiencing longer heat wave scenario than past years due to the increasing length of heat wave duration. The peak reached as at the end year (2007) of the climate base data, is slightly above eight (8) days and there is tendency that it might continue to rise beyond the recorded duration.

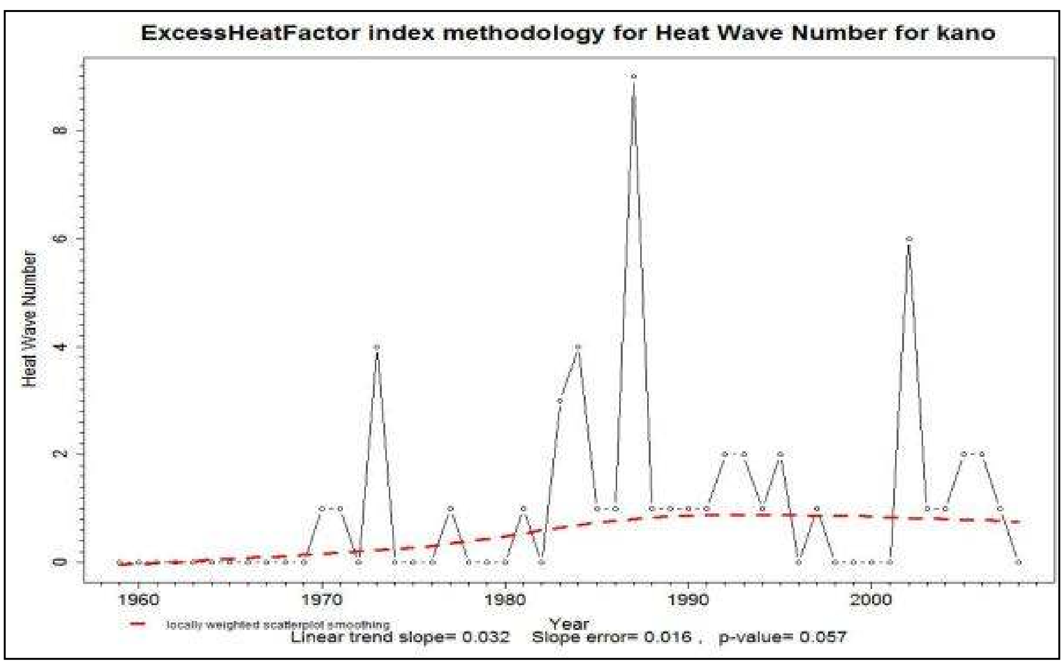


Fig. 4. Showing heat wave number in Kano as measured by excess heat factor

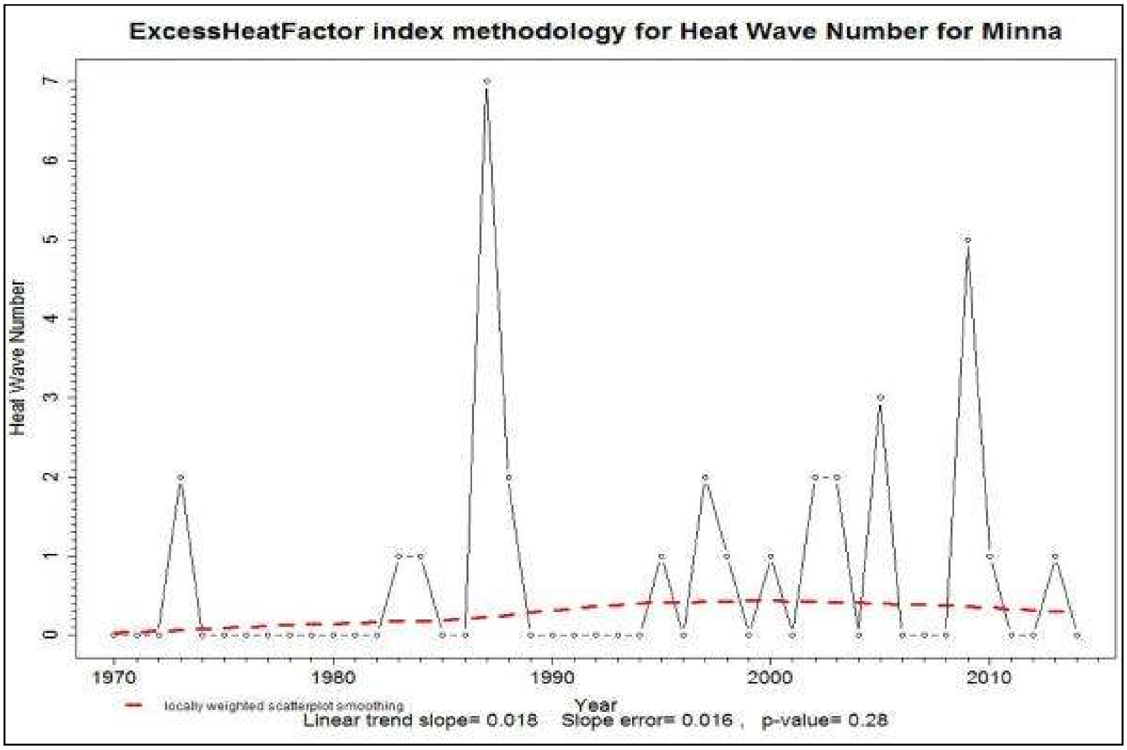


Fig. 5. Showing heat wave number in Minna as measured by excess heat factor

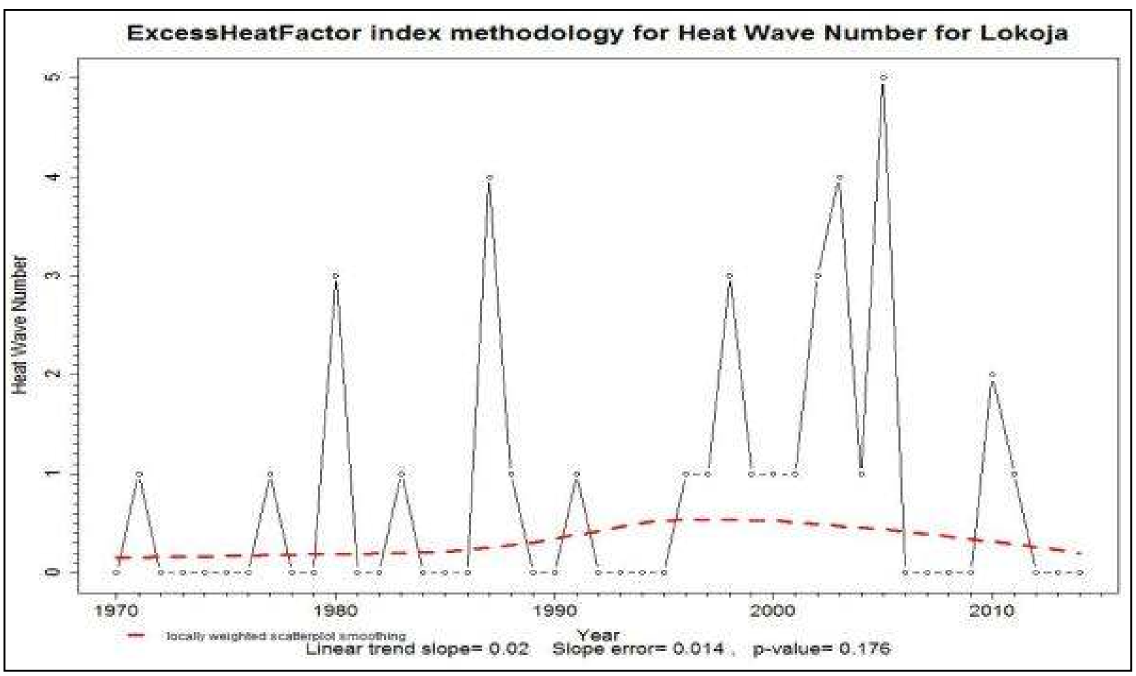


Fig. 6. Showing heat wave number in Lokoja as measured by excess heat factor

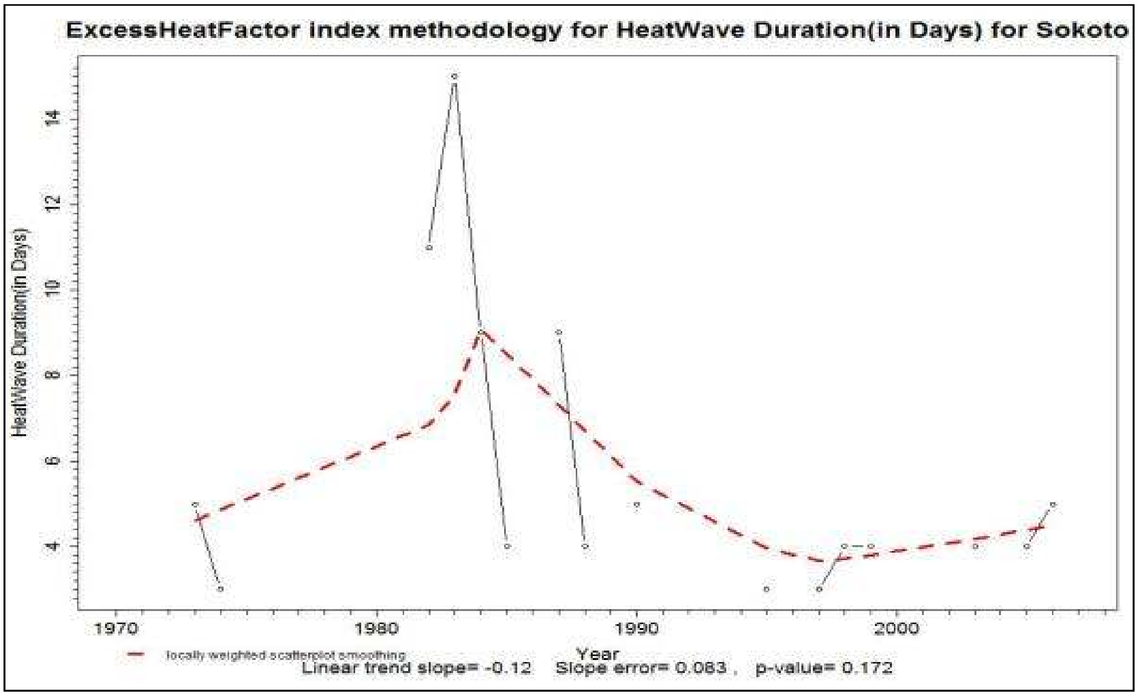


Fig. 7. Showing heat wave duration in Sokoto as measured by excess heat factor

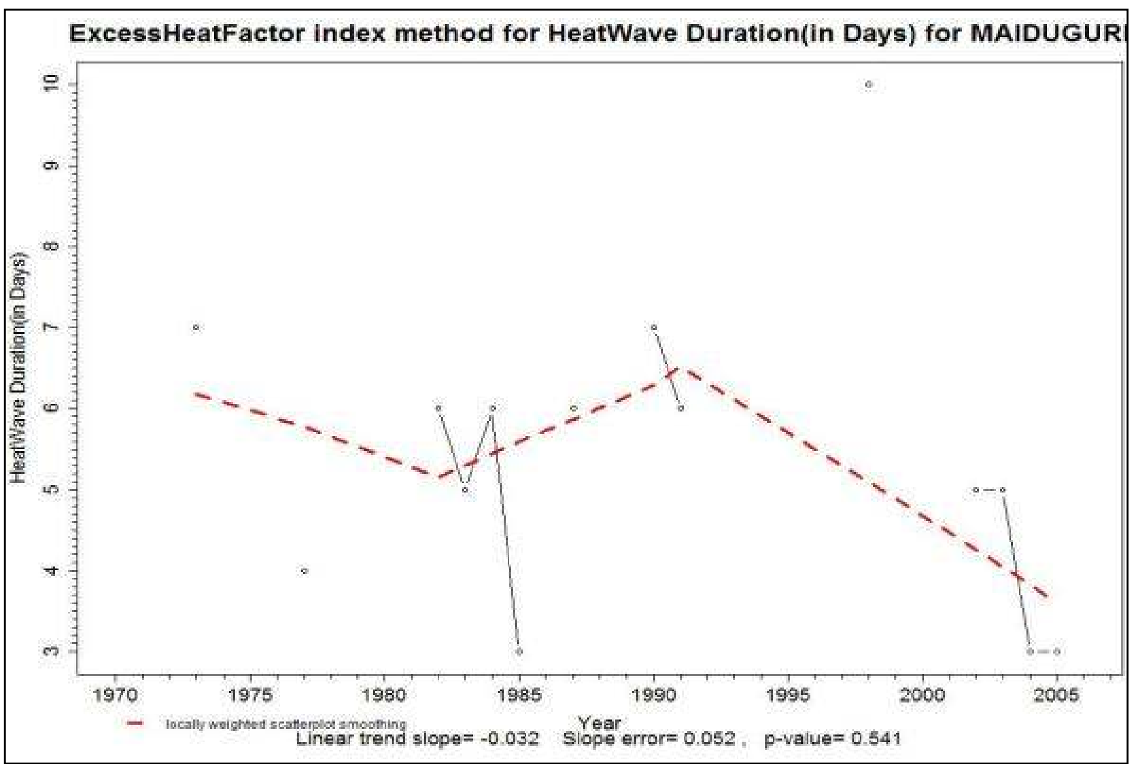


Fig. 8. Showing heat wave duration in Maiduguri as measured by excess heat factor

In Fig. 10, Minna plot indicated slight decrease or decline in heat wave duration from about 7days to close to 4 days during 1973 through 1995. Two (2) peaks, one (1) on or before 1973 and the other in 2004, were identified.

The pattern for Lokoja, as shown in Fig. 11, is similar to the pattern for Kano. Heat wave duration remained almost constant from 1971 to 1996. Thereafter, it begins to rise till 2013, which is the end year of the climate base data. The peak value reached as at 2013 is five (5) days.

3.3 Heat Wave Frequency Using Excess Heat Factor Method

The Heat Wave Frequency is the total number of days within a year that meet the heat wave criteria. Here, results that are presented indicated the total number of days in a year where the excess heat factor is greater than zero (0) which is the criteria for heat wave event. Thus, not all heat wave events actually meet the criteria for heat wave, as analysed in section 3.1. Here, we are interested in heat wave events that actually meet the criteria for heat wave.

Fig. 12, the number of days in which the heat wave criteria was met rises slightly until 1984 where it begins to fall. The pattern of this plot is similar to heat wave duration for the same station (Sokoto). Although, they both have the same unit but different number of days, the two (2) heat wave indices are not the same. The highest number of days identified as the actual heat wave events is in 1984 for Sokoto.

The Maiduguri plot, in Fig. 13, also showed similar pattern as heat wave duration in Fig. 8. The heat wave frequency decreases from 1973 to 1982 where it rises and falls again until 2005 which is the end year for the climate base period. The shortest frequency is identified in the end year of the climate data period but there is tendency that the frequency will decrease further, whereas the highest frequency of actual heat wave events comes around the start year of the climate data period. Higher frequencies were identified in Maiduguri than Sokoto for the longest actual heat wave events.

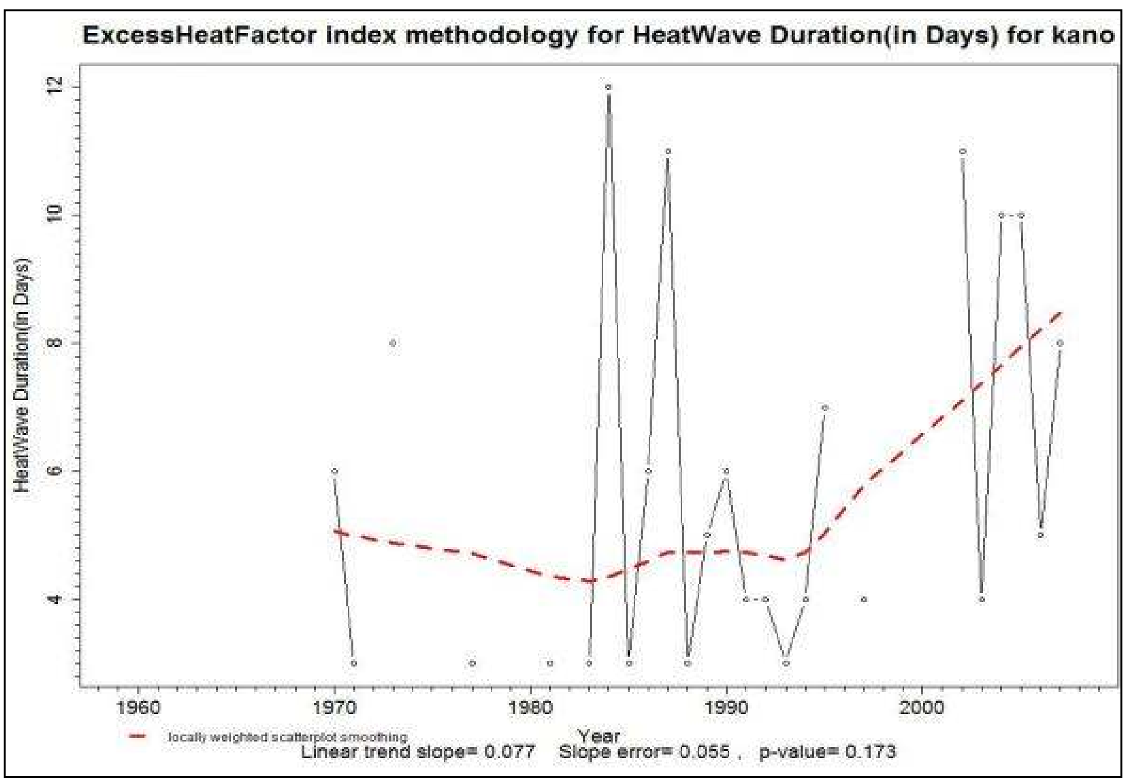


Fig. 9. Showing heat wave duration in Kano as measured by excess heat factor

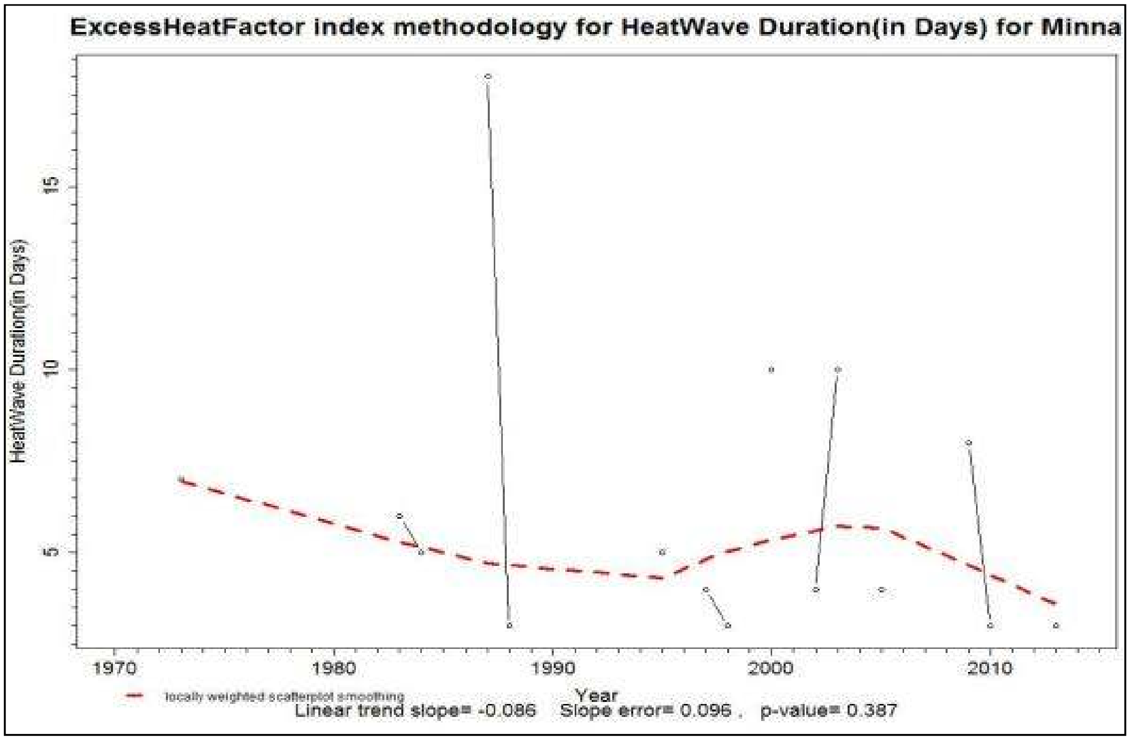


Fig. 10. Showing heat wave duration in Minna as measured by excess heat factor

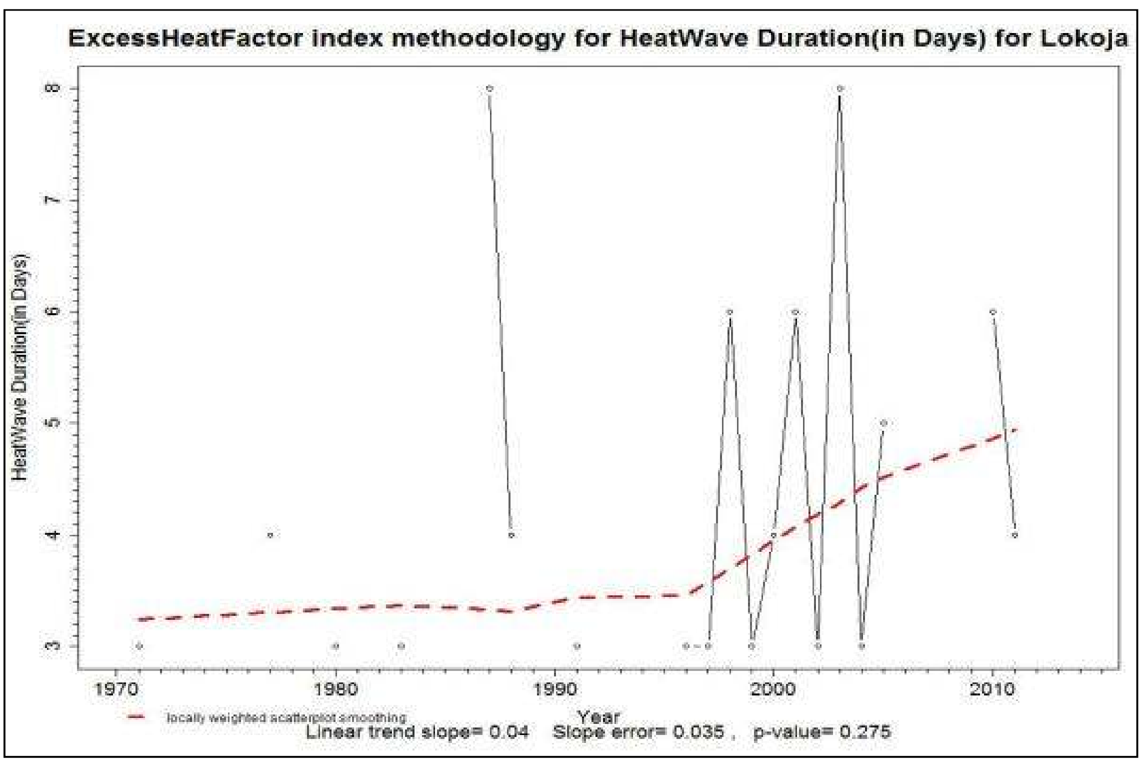


Fig. 11. Showing heat wave duration in Lokoja as measured by excess heat factor

In Kano, as shown in Fig. 14, the actual heat wave events or simply heat wave frequency does not vary much over the years. From 1970 up to 1983, the heat wave frequency remained constant at three (3) days, but begin to increase only slightly thereafter till 2007 which is the end year of the climate data period for Kano. Heat wave frequencies in Kano also are below the ones identified in Maiduguri.

Pattern of heat wave frequency in Minna, is similar to the heat wave duration discussed earlier in section 3.2. In Fig. 15, heat wave frequency decreases initially from around eleven (11) days in 1973 to close to six (6) days in 1988. The frequency remained constant at that value till 1996, it then rise slightly and fall again. The two (2) peaks at 1973 and 2003 are eleven (11) days and nine (9) days respectively, and the lowest frequency identified is close to one (1) for Minna.

In Lokoja, Fig. 16 above, heat wave frequency remained constant at about four (4) days from 1971 to 1996 where it begins to rise thereafter up to a frequency of ten (10) days in 2004. Only one (1) peak was identified in Lokoja plot, as seen above. Values were also lower compared to Maiduguri plot.

3.4 Heat Wave Amplitude Using Excess Heat Factor Methodology

The Heat Wave Amplitude is the hottest day (or peak) of an event with the highest average magnitude in a given year. The next section discusses the mean (average) magnitude, but here analysis is based on the highest value among the mean magnitude. This gives information about the hottest day during a particular heat wave event. Magnitude levels as defined by [25] is shown in Table 1.

The heat wave magnitude or amplitude decreases over the years, from 1973 to 1990, for Sokoto, as shown in Fig. 17. It remained almost constant thereafter till the end year of the climate data period. This sharp fall in hottest day during heat wave events in three (3) decades indicated that the magnitude level fell from a severe situation to close to moderate.

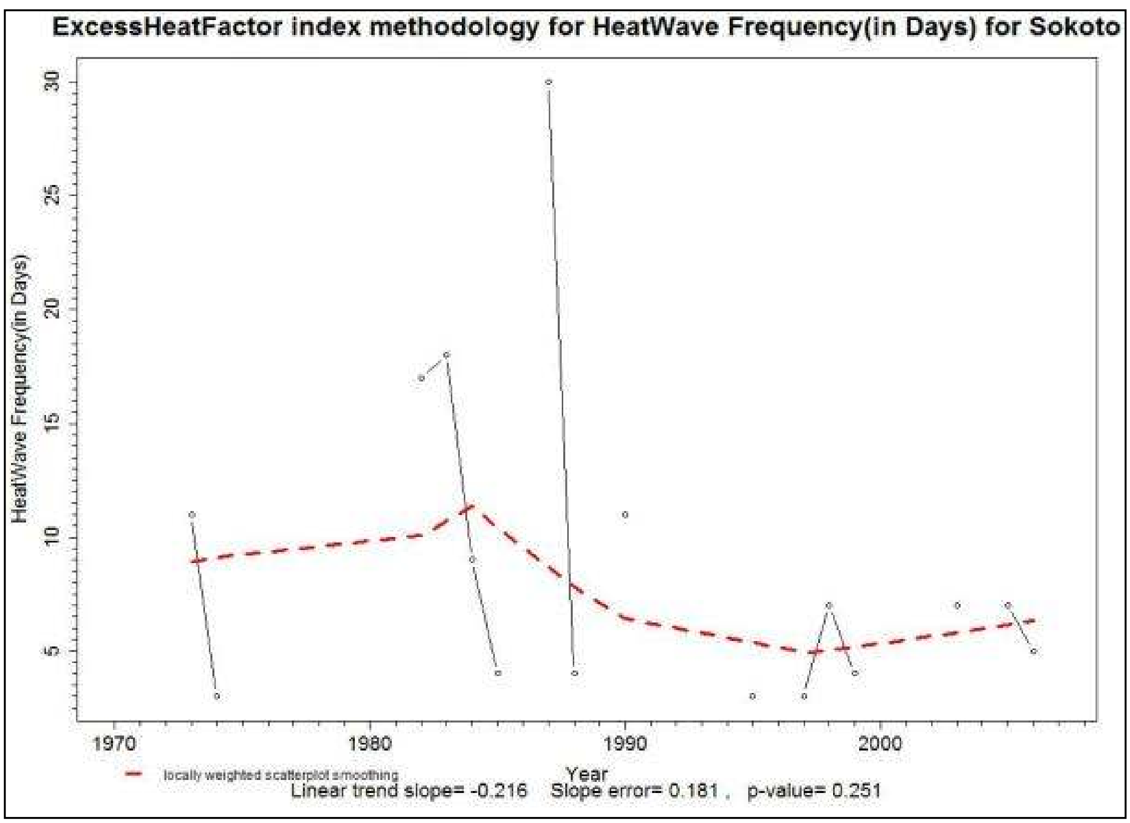


Fig. 12. Showing heat wave frequency in Sokoto as measured by excess heat factor

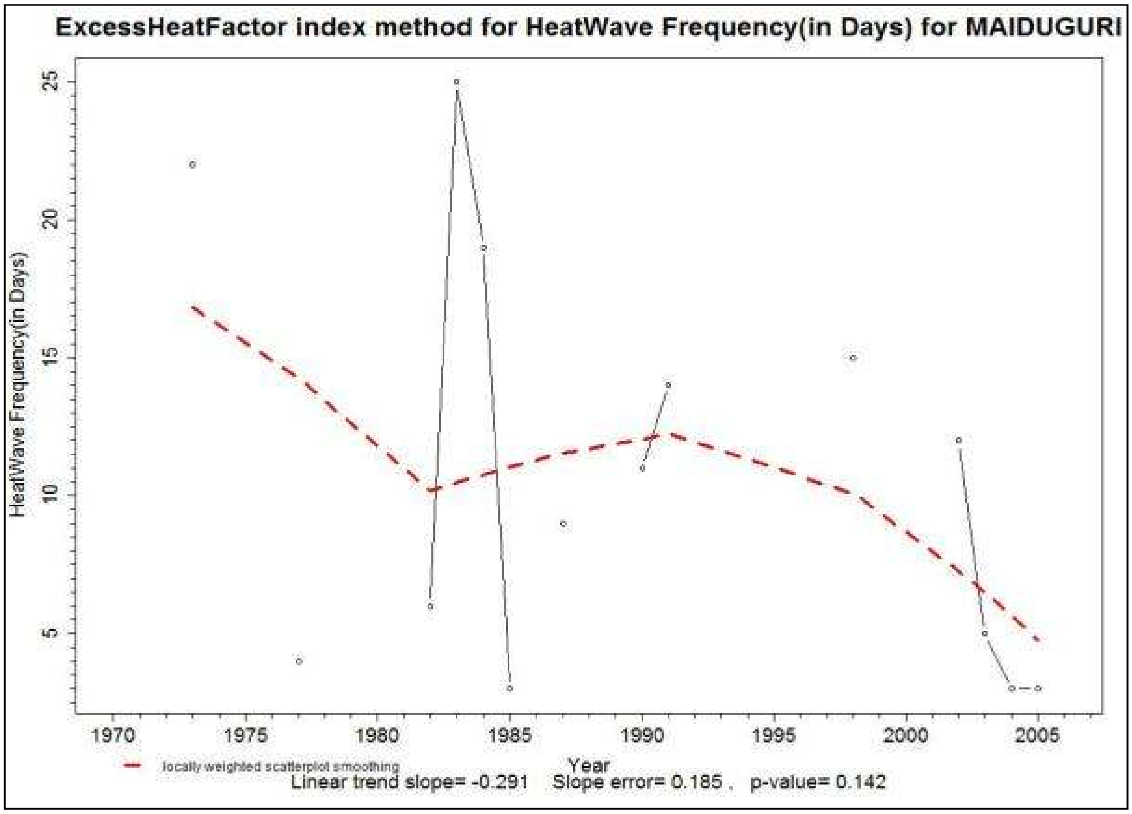


Fig. 13. Showing heat wave frequency in Maiduguri as measured by excess heat factor

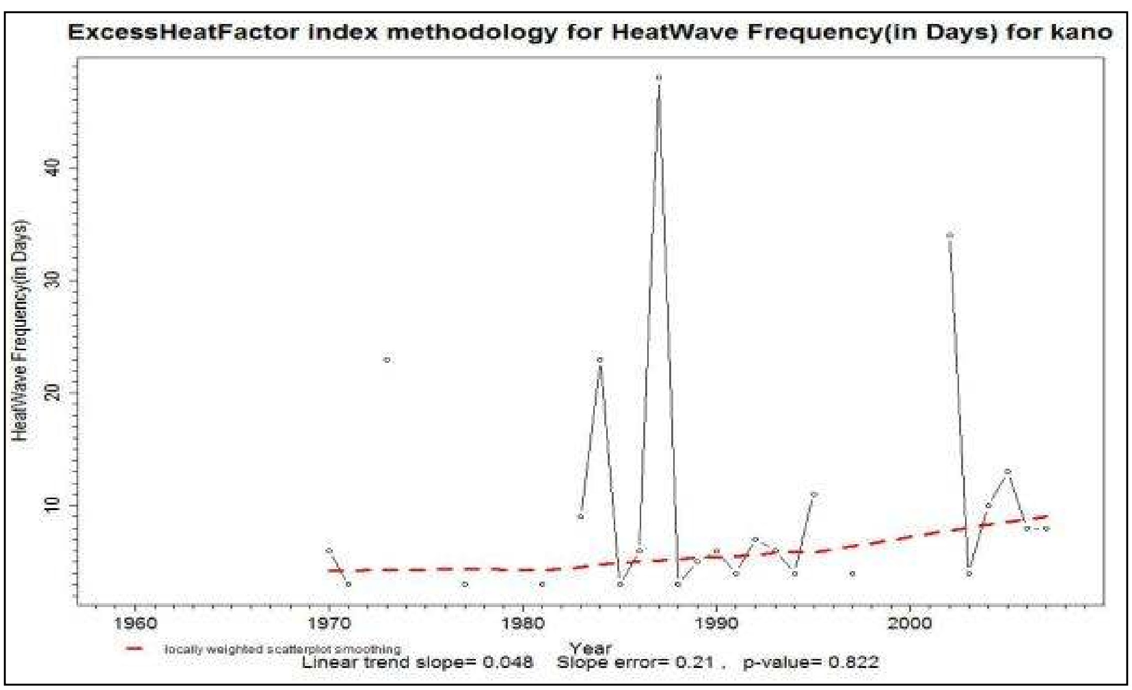


Fig. 14. Showing heat wave frequency in Kano as measured by excess heat factor

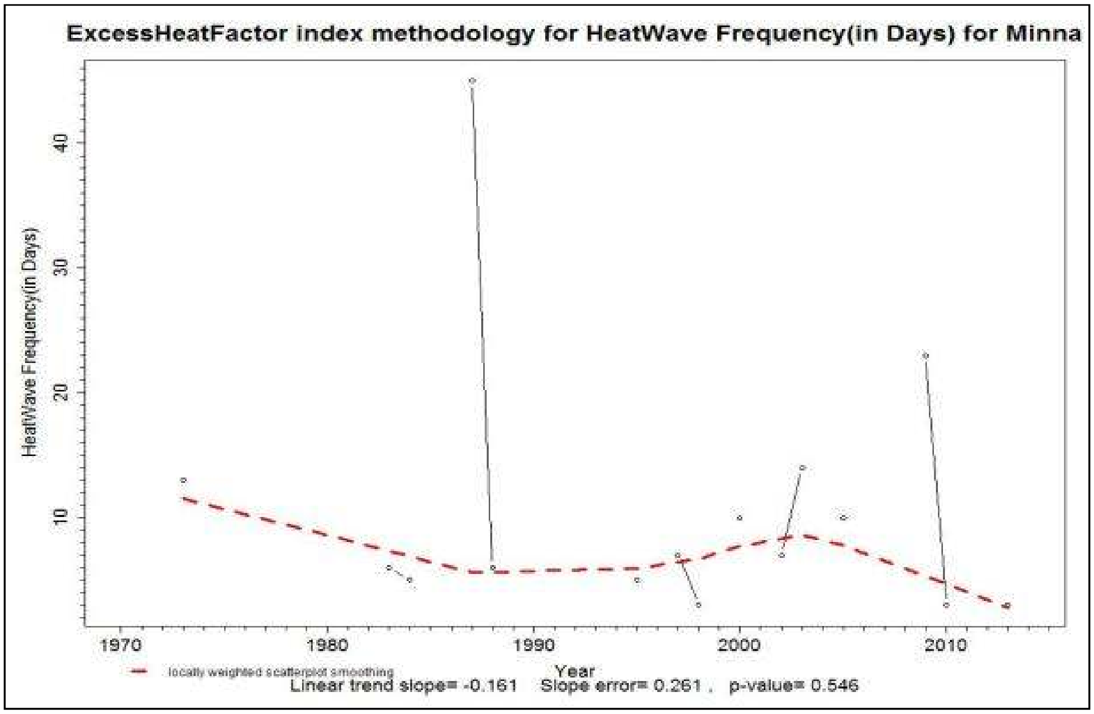


Fig. 15. Showing heat wave frequency in Minna as measured by excess heat factor

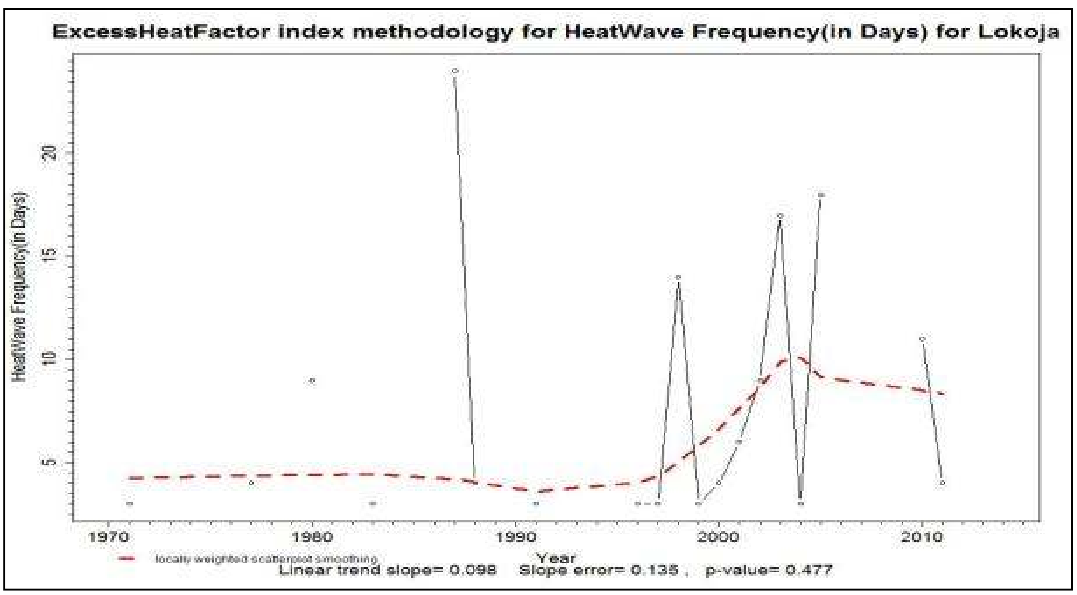
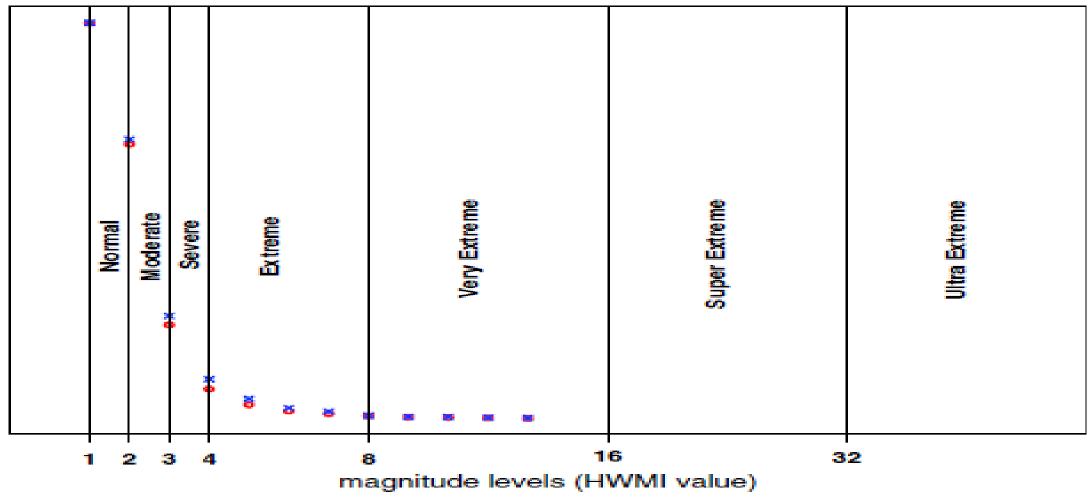


Fig. 16. Showing heat wave frequency in Lokoja as measured by excess heat factor

For Maiduguri, Fig. 18, there was a sharp decline in the magnitude level of the hottest – day heat wave events, from1973 to 1987 but the hottest – day heat wave event rises sharply again from 1987 to the end year (2005) of the climate data year used for the research. The result clearly showed that conditions are returning to how they were in the early 70s. Two (2) peaks and a single minimum were identified from the plot. As at 2005, the hottest day of heat wave event was severe in Maiduguri.

Table 1. Showing categories of heat wave magnitude levels



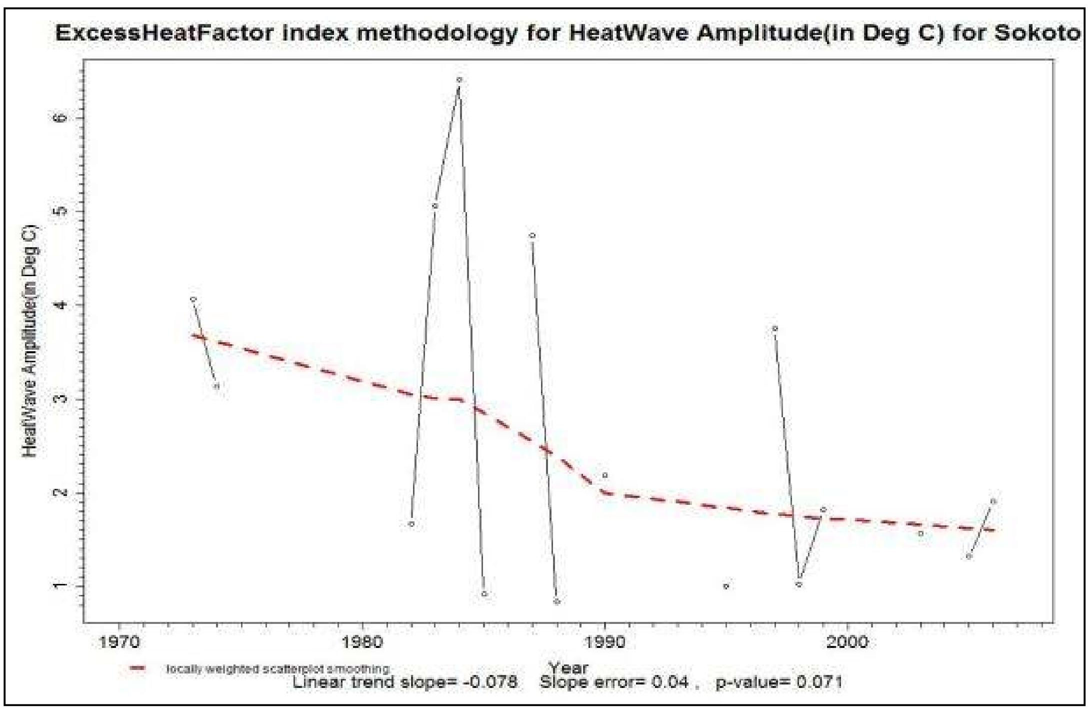


Fig. 17. Showing heat wave amplitude in Sokoto as measured by excess heat factor

Fig. 19 showed the result for Kano. Just like results from previous plots of heat wave number, heat wave duration, and heat wave frequency, the magnitude level of hottest – day for Kano is almost constant throughout the period of the climate data, but had risen only slightly. The plot indicated that the magnitude level remained moderate throughout the climate data period. This generally implied that, for Kano, heat wave cases are not common and had not been a climate issue over the years.

The hottest – day heat wave magnitude for Minna is as shown above in Fig. 20. The plot showed that there is a sharp rise in the magnitude levels of the hottest – day heat wave event, from 1973 to 1998 and a sharp fall in the magnitude levels of the hottest – day heat wave events from 1998 to 2013. The peak value of hottest – day heat wave event is at 1.5 magnitude levels, which is still a normal situation. This Minna plot had shown that hottest – day heat wave events had not gone above the normal situation over the years in Minna.

Fig. 21 shows the pattern of the magnitude levels of the hottest – day heat wave events in Lokoja. Values fluctuate below 1.0 magnitude levels throughout the climate data period. Although, the magnitude levels rises initially from 1971 to 1989, and decreases thereafter till 1996 where it begins to rise again till the end year (2013) of the climate data period, the magnitude levels remained normal throughout the period for Lokoja.

3.5 Heat Wave Mean Magnitude Using Excess Heat Factor Methodology

The Heat Wave Mean Magnitude takes the average daily magnitude across all heat wave events within the year. That is, the heat wave mean magnitude is the average taken on daily basis from the daily magnitude during all heat wave events within a given year.

The mean magnitude for Sokoto indicated a slight decline in the magnitude levels from 1973 to 1990 and an almost constant situation thereafter from 1990 to the end of the climate data period. This is shown in Fig. 22, where the least magnitude level is one (1) for Sokoto.

Just as was identified for the hottest – day of heat wave event for Maiduguri, the same pattern follows for the mean magnitude in Maiduguri. In Fig. 23, there was a decline or decrease in the in the magnitude levels from 1.2 to 0.8 during 1973 – 1986, thereafter, the magnitude level increases to 1.4 in 2005. These values still falls under the normal situation for Maiduguri.

As expected, the mean magnitude of the heat wave events for Kano as shown in Fig. 24 had remained almost constant throughout the climate base period, with just a little rise in 1994. The heat wave condition had been normal in Kano, as depicted in previous results, over the years.

The case of Minna, in Fig. 25, showed a sharp rise between 0.5 and 0.8 in the magnitude levels of the heat wave mean magnitude during 1973 – 1998, and then a sharp fall from 0.8 to 0.3 in the magnitude levels of the heat wave mean magnitude during 1998 – 2013 thereafter. In all, the heat wave condition is normal in Minna over the years.

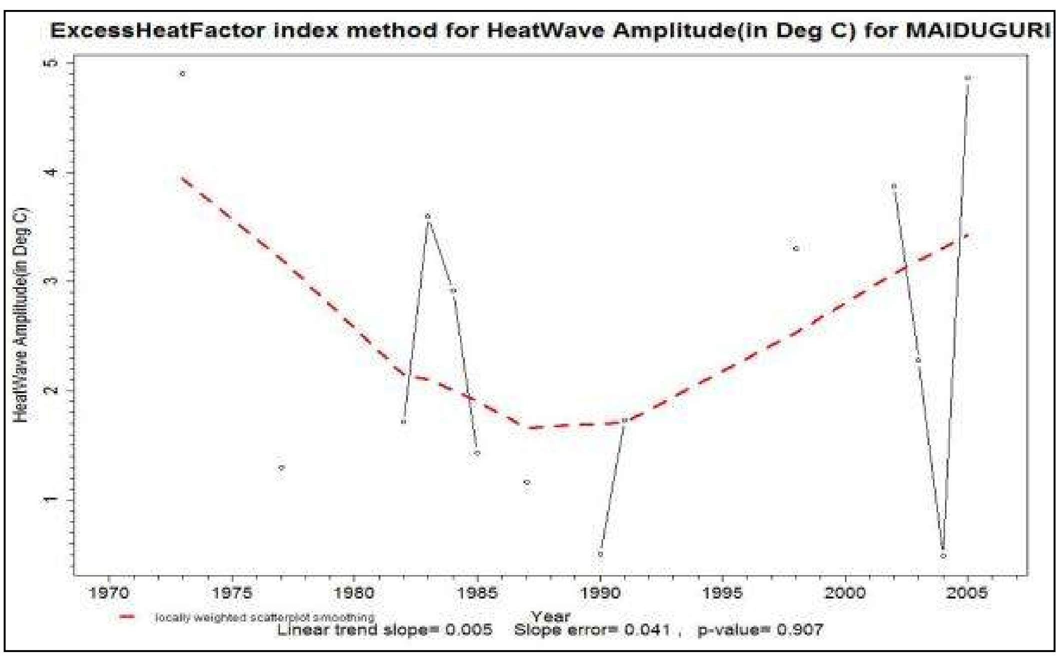


Fig. 18. Showing heat wave amplitude in Maiduguri as measured by excess heat factor

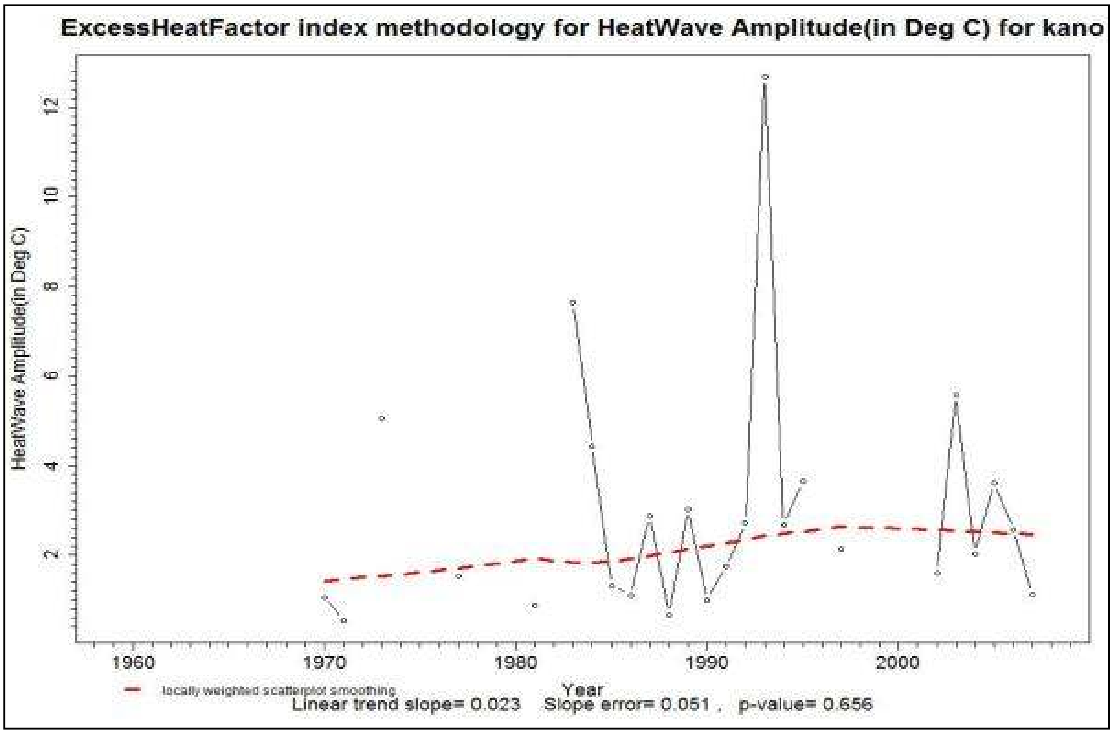


Fig. 19. Showing heat wave amplitude in Kano as measured by excess heat factor

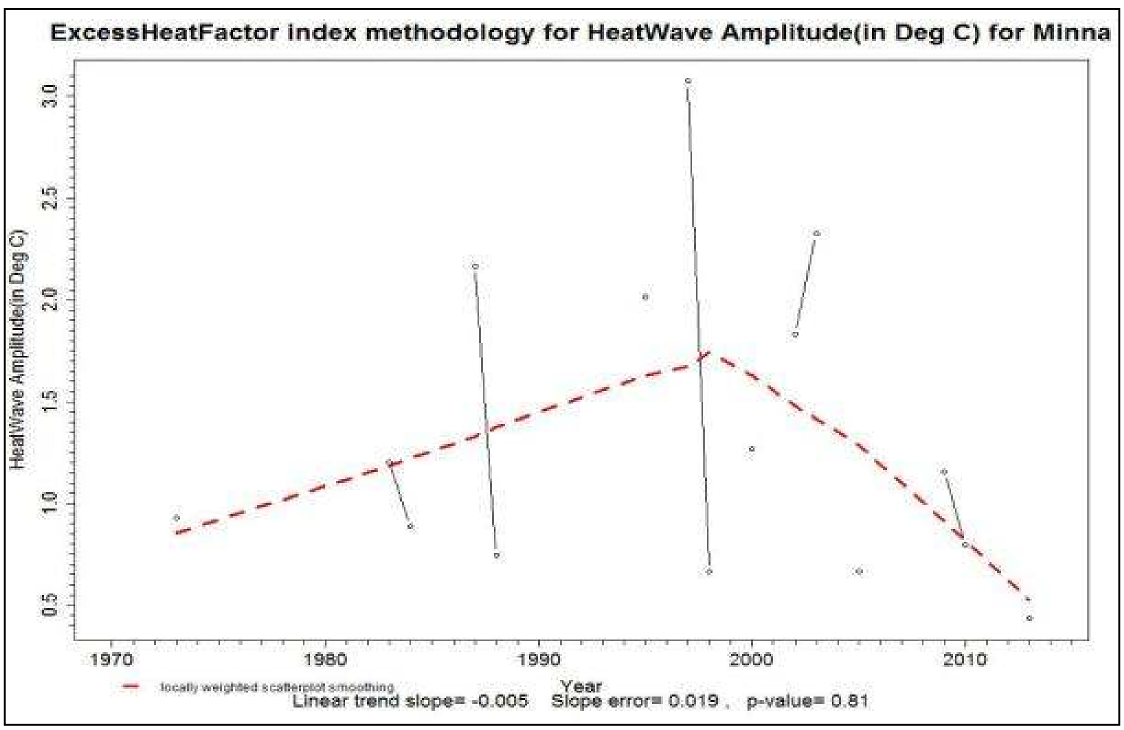


Fig. 20. Showing heat wave amplitude in Minna as measured by excess heat factor

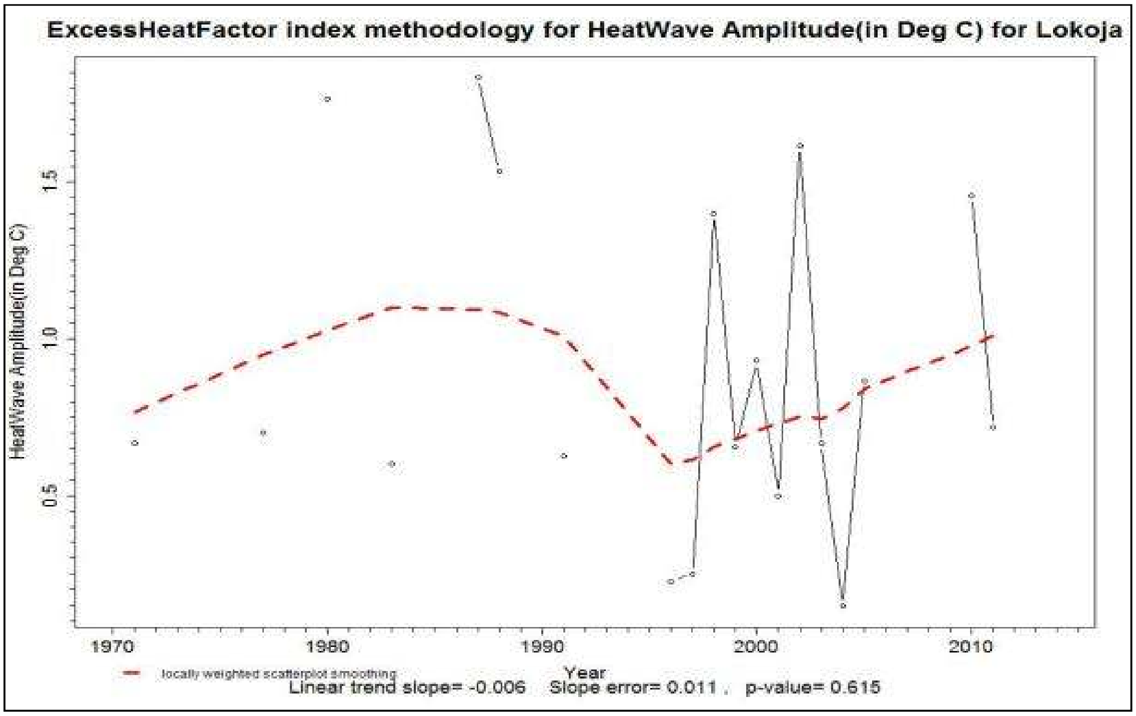


Fig. 21. Showing heat wave amplitude in Lokoja as measured by excess heat factor

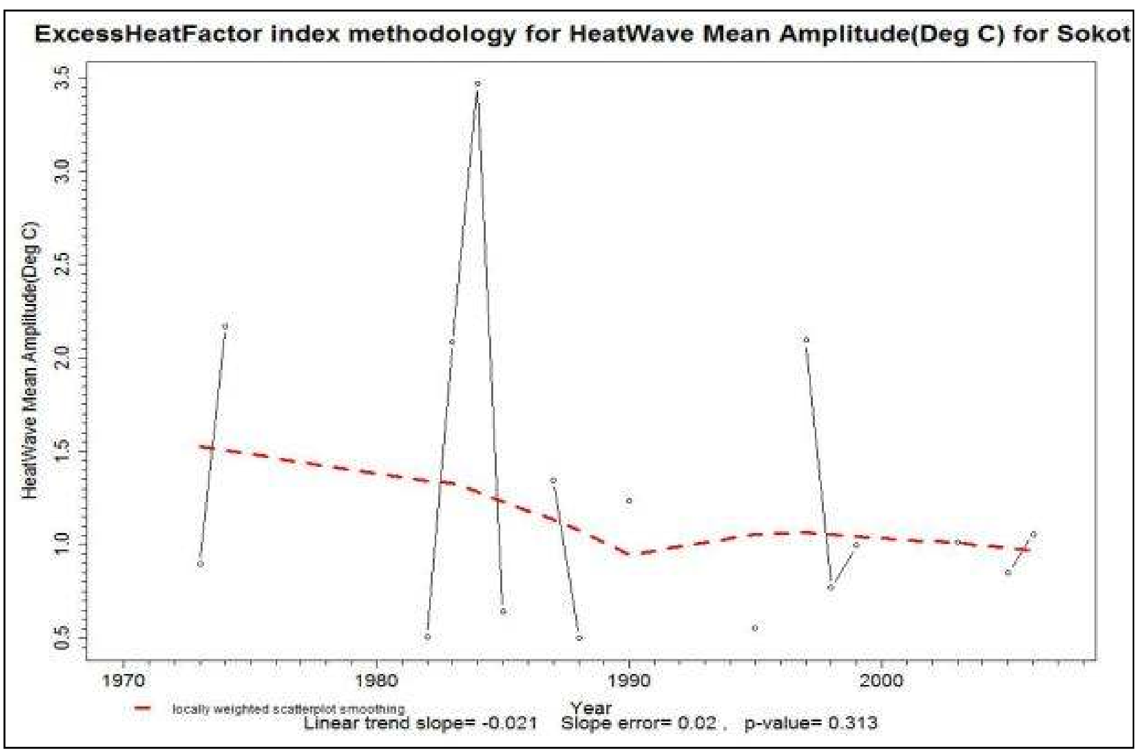


Fig. 22. Showing heat wave mean magnitude in Sokoto as measured by excess heat factor

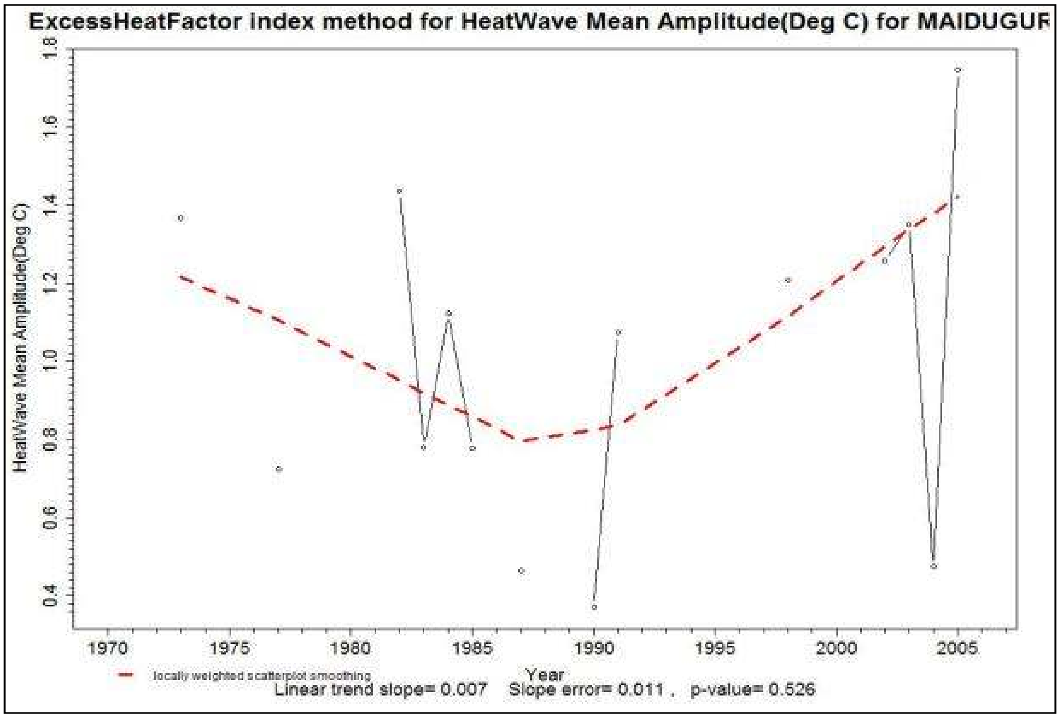


Fig. 23. Showing heat wave mean magnitude in Maiduguri as measured by excess heat factor

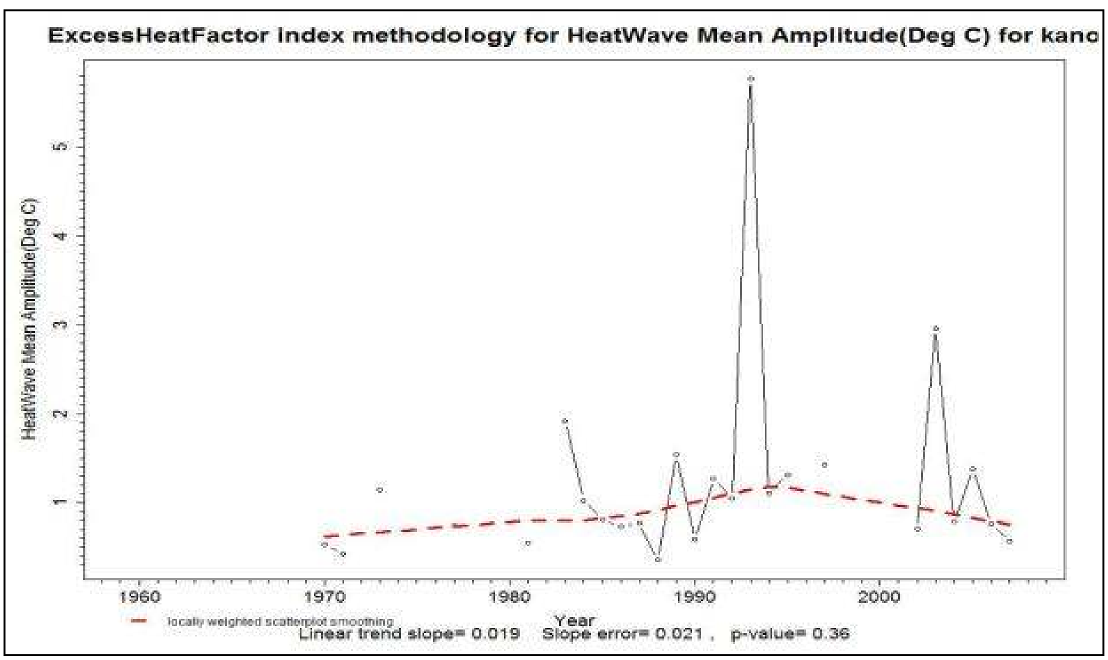


Fig. 24. Showing heat wave mean magnitude in Kano as measured by excess heat factor

Fig. 26 shows the plot for Lokoja. Magnitude levels of heat waves had remained normal over the years in this station even though plot indicated some variability. This plot further implied that heat wave condition had not grown beyond the normal condition in Lokoja over the years.

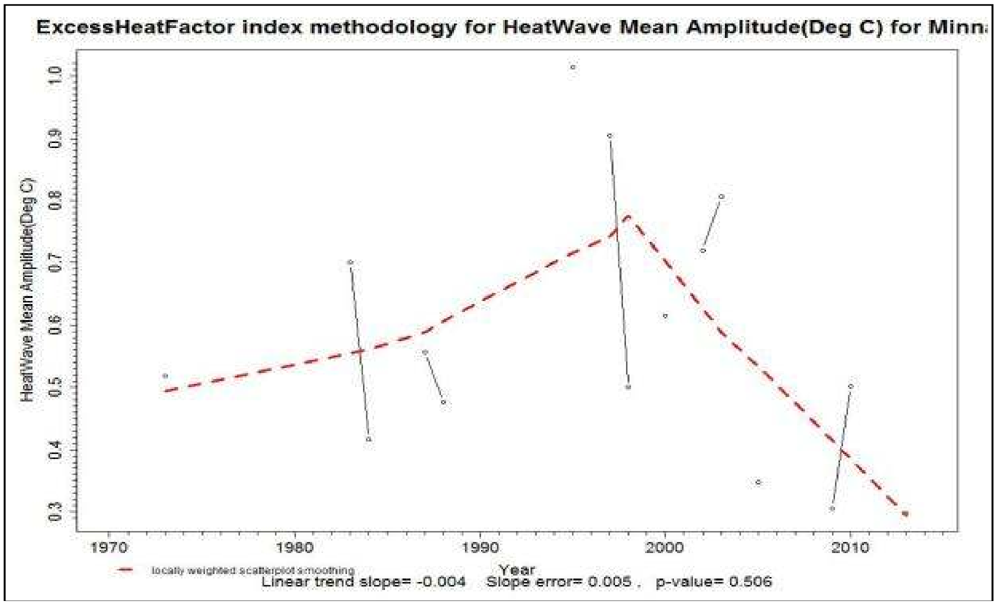


Fig. 25. Showing heat wave mean magnitude in Minna as measured by excess heat factor

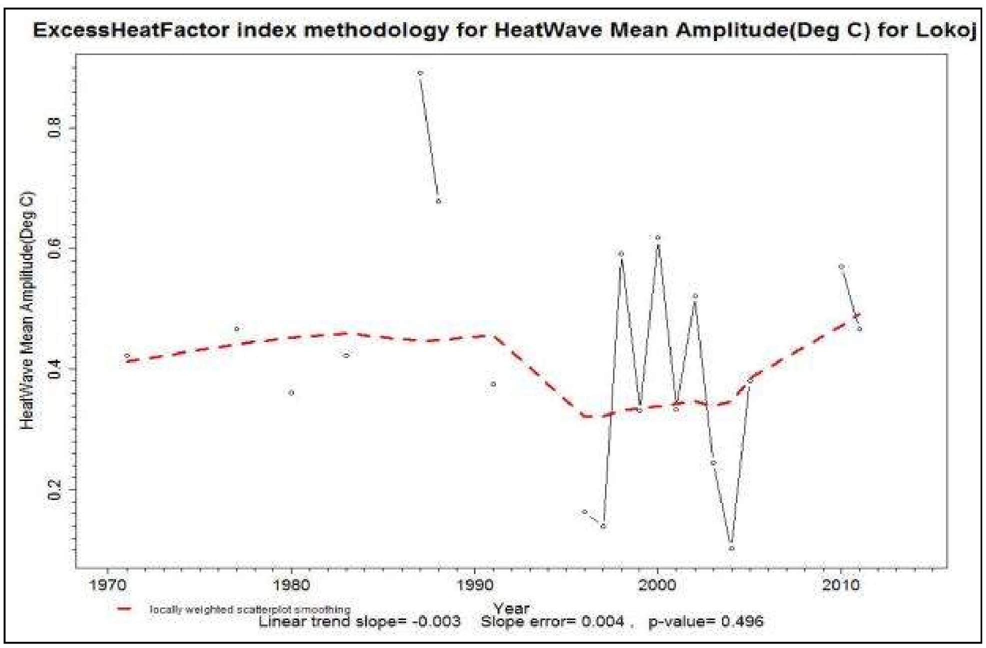


Fig. 26. Showing heat wave mean magnitude in Lokoja as measured by excess heat factor

4. CONCLUSION

This study had investigated heat wave characteristics over five (5) selected stations in Nigeria, using excess heat factor (EHF) methodology. The EHF is the combined effect of excess heat and heat stress calculated as an index to provide a comparative measure of impact, load, duration and spatial distribution of heat wave. Heat wave is scaled by magnitude of EHF (>0).

Results showed that Sokoto, Kano, and Minna had the highest heat wave number in 1987; Maiduguri had highest heat wave number in 1983 while Lokoja had highest heat wave number in 2005 and 1987. The lengthiest and shortest heat wave duration (HWD) was identified in 1983 and 1997 respectively for Sokoto, in 1991 and 2005 respectively for Maiduguri, while Kano and Lokoja had the same pattern of heat wave duration over the years. The highest heat wave frequency (in number of days) identified as the actual heat wave events was in 1984 for Sokoto. Other results indicated that Maiduguri had higher heat wave frequencies than other stations including Sokoto.

Heat wave magnitudes were classified based on magnitude levels. Results showed a decline for Sokoto both for the heat wave amplitude (magnitude) and the heat wave mean magnitude. For Maiduguri, the magnitude levels decreases initially and increases over the climate data period for both the heat wave amplitude and mean magnitude. Whereas, in Kano there was an almost constant heat wave amplitude and mean magnitude condition over the years. In Minna, opposite conditions as against Maiduguri were identified, in which the magnitude levels increases initially and deceases thereafter for both the heat wave amplitude and mean magnitude. Sokoto and Maiduguri had close to severe conditions based on their magnitude levels for both the heat wave amplitude and mean magnitude.

All results from the five heat wave characteristics indicated moderate conditions, since severe or even extreme cases rarely occurred. This implied that the southern Sahel and the savannah stations investigated in this study have not been highly affected by heat wave conditions but at some moderate levels over the years under investigation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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