CLIMATE CHANGE INDICATION ACROSS FOUR STATES IN NIGERIA: HEAT LOAD INDEX AND MULTIVARIATE ANALYSIS

TOWOLAWI, A.T.[1*], OGUNTOKE, O.[2], BADA, B.S.[2], ADEJUWON, J.O.[3], ABDULSALAMI, B.A.[4], AND ADEGBORE, A.K.[5]

[1]*Department of Environmental Health Science, Fountain University Osogbo, Osun State, Nigeria;*
[2]*Environmental Management and Toxicology, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria;*
[3]*Water Resources Management and Agrometeorology, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria;*
[4]*Mathematical and Computer Sciences, Fountain University Osogbo, Osun State, Nigeria;*
[5]*Department of Public Health Science, Fountain University Osogbo, Osun State, Nigeria*
**Corresponding author: taofiktowolawi@yahoo.com, attowolawi@fuo.edu.ng, +2348060172946*

ABSTRACT

Biometeorologists typify climate change indication on the environment using indices such as the heat load index (HLI) with scales of HLI: ≤ 70.0 for cool, 70.1 to 77 for warm, 77.1 to 86.0 for hot, and ≥86.1 for a very hot environment. The current study adopted HLI computed from temperature, relative humidity, and wind speed data of 32 years (1987-2018) for five locations (Benin, Ondo, Bida, Minna, and Makurdi) and their environs, where rain-fed agriculture does favour yearly agricultural produce. The data were retrieved from the archive of Nigeria Meteorology office, Abuja, analysed with descriptive statistics, and further subjected to multivariate analysis. Average HLI indicated a hot environment for the wet periods except for April, when it was warm at Minna. December to February of dry periods had cool environments in Bida, Niger, Makurdi and their environs. Very strong correlations occurred from April to June, between September and October, and between November and December at a 0.01 significant level from Pearson's Correlation. The Principal Component Analysis indicated eleven months with 61.00 % variance under Component 1, and four months (January, July, September, and October) among them had eigenvalue less than 0.8, indicating that the entire year except August had climate change indications. The study suggested that the five locations and their environs must understand how to cope with climate change heat load.

Keywords: ***agro-ecological zone, biometeorology, heat stress, rain-fed agriculture***

INTRODUCTION

Assessing climate change (CC) indicators involves identifying and evaluating risks related to specific cases and their causal factors and assessing the intensity, duration, and vulnerability. Such assessment can be achieved through gathering secondary data from meteorological and related agencies, analysing and interpreting the gathered data, and crafting strategies for appropriate mitigation (Wilhelmi *et al.*, 2004). Increased temperature in the tropical region is a risk that necessitates evaluating how the area experiences and responds to high heat exposures (Frinpomg, 2015); increased temperature indicates the reason that organisms are susceptible to stress when growing or before maturity (Spiers *et al.*, 2004). Early productivity of organisms relies on the chance of using energy sources, while the later productivity is due to the energy used from available sources of nutrients in the environment (Bernabucci *et al.*, 2010). Scholtz *et al.* (2013) affirmed that though success had been recorded for high-yielding agricultural produce from various adaptation strategies, environmental factors (or the climate elements: ambient temperature, humidity, solar radiation and wind) are still affecting the agricultural produce (Hulme, 2005). High humidity conditions inhibit respiration and evaporation in animals and plants, respectively. Wind lowers the impacts of increased temperature, while solar radiation intensifies stress on metabolic processes (Silva *et al.*, 2007). Aharoni *et al.* (2002) and Mader *et al.* (2006) affirmed that critical temperature would fluctuate and be subject to other factors (wind, relative humidity) to determine the acclimatisation, rate of production and germination status of living organisms. The study of West (2003) showed that variability in climate elements (solar radiation, wind speed, and their interactions) influenced the performance of some tested subjects.

Weather forecasts using minimum and maximum temperature and relative humidity values are valuable for understanding the CC indication (NOAA, 2002). Studies have recently focused on heat load as a CC stress indicator and a risk to public health. Many indices portrayed the influence of climate elements on biotic organisms (e.g., plants and animals). Some indices are heat load, heat stress, the wet bulb globe temperature and universal heat index. Applying new bioclimatic indices enables the use of humidity, temperature, wind speed, and solar radiation directly in various subjects and heat stress equations. Heat indices are tools of the Department of Public Health and Meteorological Agency to notify the public when they reach the individual or joint danger of temperature and humidity. Different stress indices are available for adoption to measure the potential impact of heat loads on humans (Parsons, 2003; Kjellstrom, 2009). An increase in the number of warm nights with humidex was indicated in the study of Mekis *et al.* (2015). Several commonly used heat indices depend on the adopted climatic elements, the available meteorological data, ease of use, and historical precedence in the area under study.

Findings of research on heat stress via the CC revolved around temperature and relative humidity (Bouraoui *et al.*, 2002; Correa-Calderon *et al.*, 2004) due to inadequate availability of thermal radiation, wind speed and rainfall data. Daily weather (temperature and relative humidity) data from the website were used as measured weather elements (NCDC, 2013; Pradhan *et al.*, 2013). Analysing three periods of future climate projections for 15 cities, Martin *et al.* (2011) concluded that there would likely be increasing heat-related issues. Le Roy Ladurie (2004) traced extreme heat from historical indicators, while Chuine *et al.* (2004) adapted a regional index. Time series analysis established an unrelenting global upturn in scorching days on land (Seneviratne *et al.*, 2014). A positive correlation occurred between the dry-bulb temperature, solar radiation, relative humidity and respiration rate predictor with biological reactions (Ingram and Mount, 1975; Eigenberg *et al.*, 2000). However, the study of Mader and Davis (2002) recorded a negative correlation between wind speed and respiration.

Trends of heat stress events (Sippel and Otto, 2014) and frequency of the heat stress events (Battisti and Naylor, 2009; Willett and Sherwood, 2012) were observed to likely increase in the future across the tropics and parts of the mid-latitudes, respectively, using climatic elements. Different climatic elements (such as relative humidity, wind speed, and fluxes in both short- and long-wave radiation in addition to temperature) help monitor possible effects of the CC (Steadman, 1984). The combined climatic elements contribute more to the CC indication than the single predictive element and variable temperature (Oechsli and Buechley, 1970). Three climatic elements (temperature, relative humidity, and wind speed) computed the heat load index being considered in this study.

This study aimed to verify climate change indications using the established heat load index across five locations and their environs, where agriculture is mostly their profession. The outcome could be a baseline or an integral part of information for the agricultural and health-related stakeholders to implement the sustainability campaign of the UNEP (2020).

MATERIALS AND METHODS

Secondary data were adopted to assess climate change indications using an established heat load index (HLI) across five purposively chosen locations across four Nigerian States. The HLI is computed from secondary data of three climatic elements (temperature, relative humidity and wind speed) of 32 years. The HLI has four categories to describe environmental conditions as cool (≤70.0), warm (between 70.1 and 77.0), hot (between 77.1 and 86.0), and very hot (≥86.0). The four (Benue, Edo, Niger and Ondo) States, which the study purposively considered, are known in Nigeria to be highly productive for yearly agricultural produce and indirectly feeding the nation. The monthly climatic elements (wind speed, relative humidity and temperature) of 32 years across five locations and their environs (i.e., Makurdi in Benue, Benin in Edo, Bida and Minna in Niger and Ondo in Ondo States) were procured from the archive of Nigeria Meteorology, Abuja, Nigeria.

Heat load index (HLI)

The heat load index (HLI) was developed by Gaughan *et al.* (2002) and was based on relative humidity (RH %), wind speed (V m/s), and predicted globe temperature (Tg∗ °C). HLI is expressed in equation form as shown in Equation 1a – 1d:

$$HLI = 33.2 + 0.2RH + 1.2Tg_{*} - (0.82V)^{0.1} - \log(0.4V^{2} + 0.0001) \quad \text{------ (1a)}$$

$$Tg_{*} = 1.33T - 2.65T^{1/2} + 3.21\log(SR + 1) + 3.5 \quad \text{------ (1b)}$$

The SR denotes solar radiation. HLI has been modified (HLI New) by Gaughan *et al.* (2008) to two formulae based on a global temperature above and below 25 °C. The classification by HLI can be in four categories: cool (≤70.0), warm (between 70.1 and 77.0), hot (between 77.1 and 86.0), and very hot (≥86.0). However, Silva et al. (2007) showed that the following version of the HLI was the best thermal stress index under tropical conditions.

$$T^{*}g < 25\,^{\circ}C; \quad HLI_{New} = 10.66 + 0.28RH + 1.3Tg_{*} - V \quad \text{-------- (1c)}$$

$$T^{*}g > 25\,^{\circ}C; \quad HLI_{New} = 8.62 + 0.38RH + 1.55Tg_{*} - 0.5V + e^{2.4-V} \quad \text{------- (1d)}$$

Statistical Analysis

The monthly HLI is computed from three climate elements (average temperature, relative humidity, and wind speed) for 32 years, and the values were tabularised for each location. The average HLI values over the 32 years were calculated for each month using descriptive statistics. The Analysis of variance was used to compare the five study locations and their environs, and the Duncan Multiple Range Test separated the average HLI. Pearson's correlation and principal component analysis were also carried out on the obtained average HLI values using SPSS version 23.

RESULTS

Weather conditions in Benin (Edo State) and its environs were observed to be hot (HLI was between 77.1 and 86.0) for 12 months in 13 years, including the recent three years (2014, 2016 and 2018). There was also an observation that a 2-month period (March and April) in 2005 and a 7-month period (Feb.–June, and Oct.-Nov.) in 2007 had very hot weather conditions (HLI ≥ 86.00) (Table 1). Ondo's (Ondo State's) weather conditions were hot (HLI: between 77.1 and 86.0) for 12 months in 10 years with successional three years: 2001, 2002 and

2003. Very hot (HLI ≥ 86.00) weather conditions occurred in 2004 (Oct.-Nov.), 2005 (March-May), 2006 (March-May, Aug. and Nov.), 2014 (November and December) and 2015 (May and Nov.) (Table 2).

Table 1: Computed HLI for Benin Mets (Edo State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	79.39	81.81	81.49	81.52	81.52	80.59	80.48	81.51	81.43	81.31	81.92	79.37
1988	77.69	83.02	81.16	82.73	81.83	81.57	80.76	80.31	81.75	82.97	81.88	78.39
1989	68.53	74.81	80.91	81.37	81.00	80.74	80.20	79.84	79.58	81.31	81.65	78.67
1990	80.11	77.88	80.78	80.66	80.36	80.76	80.35	79.16	80.67	80.36	81.30	82.15
1991	77.59	85.38	82.25	80.64	81.95	83.15	81.49	80.34	80.34	79.94	82.65	76.88
1992	68.91	77.50	80.25	81.22	81.30	80.38	80.54	78.28	79.61	80.62	76.93	77.03
1993	69.42	78.40	78.93	80.42	81.28	81.73	78.97	80.31	81.50	80.35	81.64	77.50
1994	75.79	79.35	82.08	81.11	81.31	80.56	80.14	80.44	81.35	81.17	80.02	71.00
1995	75.43	80.87	81.75	82.02	81.70	81.77	81.09	81.22	81.30	80.50	79.97	79.25
1996	83.06	82.83	82.89	82.19	81.72	81.50	80.54	81.39	80.50	81.32	79.82	81.71
1997	79.57	74.95	80.00	80.95	81.58	80.99	79.29	80.31	81.46	81.49	83.06	80.99
1998	72.51	79.85	80.59	82.56	82.47	81.77	82.00	78.94	81.36	81.86	81.43	79.15
1999	78.63	81.22	82.11	81.32	81.53	81.75	82.35	79.63	80.63	81.98	81.53	79.52
2000	79.58	72.95	80.36	80.68	81.29	81.73	80.74	81.35	81.37	83.41	82.07	76.33
2001	79.44	77.92	82.30	80.27	81.87	82.11	82.18	79.81	80.70	81.31	82.49	82.38
2002	72.96	79.28	84.95	82.70	81.71	81.12	81.90	81.00	81.38	81.66	82.11	75.75
2003	80.52	81.68	82.32	81.37	82.33	81.25	79.69	79.71	83.01	82.58	81.85	78.46
2004	78.52	77.56	80.36	80.30	81.39	80.74	80.43	80.39	82.32	82.36	82.92	81.61
2005	75.53	85.73	89.20	87.80	85.43	85.12	84.51	81.72	82.94	84.29	84.21	82.00
2006	83.97	83.24	81.86	82.37	81.70	82.48	81.78	80.17	81.22	82.57	82.43	76.67
2007	75.72	90.82	90.92	92.26	91.45	88.46	84.91	84.33	84.30	86.90	86.58	78.55
2008	64.76	66.61	75.37	76.17	77.66	78.71	78.66	77.06	79.25	75.95	75.72	72.18
2009	82.30	83.85	84.12	82.03	81.88	83.22	83.10	81.65	83.83	83.15	84.41	84.47
2010	87.00	87.30	87.33	85.28	85.10	84.89	82.48	82.27	84.64	84.63	85.04	84.67
2011	70.76	80.31	82.65	80.61	80.32	79.73	80.23	79.23	79.90	79.00	77.76	71.96
2012	72.24	79.37	78.47	78.52	82.09	79.61	79.84	78.64	81.75	80.62	80.82	79.31
2013	76.42	77.30	80.51	80.64	80.99	80.14	78.96	78.67	79.75	80.77	80.36	77.45
2014	81.45	81.23	82.20	82.30	82.32	82.28	80.71	78.90	81.13	81.59	82.92	82.41
2015	75.08	78.98	80.02	85.07	82.68	82.55	80.36	78.11	79.52	80.61	76.50	78.90
2016	80.06	85.73	84.22	85.53	85.46	82.28	82.04	81.35	82.07	83.24	84.19	81.27
2017	74.47	76.06	79.85	79.97	79.48	80.32	78.67	78.60	79.37	79.15	79.05	76.80
2018	83.44	84.60	83.88	81.93	83.09	83.32	80.57	80.78	82.93	84.52	85.68	84.51

MetS: meteorological station, HLI: heat load index, **cool** (HLI≤70.0), **warm** (between 70.1 and 77.0), hot (between 77.1 and 86.0), and **very hot** (HLI ≥86.0).

Table 2: Computed HLI for Ondo Mets (Ondo State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	79.03	80.04	80.13	80.75	80.25	78.73	79.67	81.09	81.14	81.71	83.03	78.23
1988	78.53	79.50	81.00	80.43	80.24	79.59	78.08	77.53	79.53	81.32	81.45	80.29
1989	71.28	75.74	79.91	80.71	80.69	80.65	79.65	78.68	81.35	81.42	84.72	82.32
1990	80.82	77.79	79.81	81.52	80.88	82.63	79.70	78.71	79.61	81.87	83.56	81.22
1991	80.89	81.48	83.43	82.45	81.92	81.50	80.52	77.90	80.11	79.45	84.21	77.84
1992	68.71	76.04	81.13	81.14	83.02	79.73	79.94	77.41	80.32	80.44	77.50	79.89
1993	70.65	79.84	77.00	80.50	81.65	80.81	78.17	78.68	79.99	80.59	84.92	79.90
1994	73.19	75.92	76.40	77.65	77.69	77.87	79.23	76.91	77.77	74.65	72.03	76.27
1995	72.20	80.27	80.13	80.65	80.61	79.88	78.53	79.36	78.54	80.54	80.32	79.43
1996	81.97	79.81	79.71	80.11	79.92	81.98	78.53	78.60	79.06	81.41	81.63	84.80
1997	80.51	72.06	79.47	81.30	84.27	85.41	78.38	79.20	82.46	82.58	83.24	84.54
1998	75.64	79.12	83.83	83.26	82.59	83.59	81.23	77.74	79.75	82.78	84.41	79.83
1999	78.85	79.29	81.15	80.69	80.89	81.46	79.06	75.20	79.31	80.71	81.49	74.79
2000	81.21	69.69	78.27	81.34	81.52	83.38	79.57	81.40	81.57	79.34	78.92	78.47
2001	81.94	77.36	83.24	86.69	88.81	83.60	82.05	80.88	82.79	79.70	80.55	79.53
2002	78.65	81.89	86.01	85.62	85.63	82.37	84.94	83.75	82.31	80.26	78.66	78.34
2003	80.42	82.70	83.88	86.53	84.65	83.33	79.15	79.94	84.96	84.55	85.57	84.39
2004	85.68	81.07	81.23	82.95	84.61	83.54	79.81	81.57	83.55	90.52	91.58	86.41
2005	74.27	83.53	90.94	87.36	89.07	83.93	83.26	79.36	84.22	86.63	86.06	89.87
2006	84.15	84.51	89.06	86.69	89.24	85.91	82.26	80.11	86.94	82.70	87.32	79.87
2007	71.84	80.00	81.76	82.30	83.22	81.13	84.17	78.52	82.47	84.68	84.64	80.48
2008	64.54	67.19	74.03	77.14	76.73	78.37	80.58	79.32	82.64	80.27	78.49	74.90
2009	74.29	75.83	77.12	78.92	79.62	79.58	79.33	84.30	85.63	86.04	79.94	84.11
2010	82.60	83.00	79.69	81.88	83.16	84.22	81.94	81.29	82.25	82.19	78.26	77.37
2011	72.04	80.01	80.11	80.21	80.96	82.00	80.10	81.66	82.96	82.13	78.31	72.23
2012	75.05	79.54	82.35	83.97	82.15	82.88	81.13	81.20	82.99	82.59	82.19	76.79
2013	78.73	80.32	79.91	82.34	82.08	82.83	79.71	81.88	82.66	83.32	82.37	79.34
2014	74.67	76.98	80.51	81.78	81.97	83.08	81.46	77.98	79.97	81.96	87.18	86.26
2015	72.76	82.35	82.92	84.11	86.49	83.99	82.13	81.06	81.14	85.32	88.92	82.06
2016	72.74	71.64	77.09	79.84	79.96	81.84	81.66	78.22	78.85	80.80	83.01	80.85
2017	76.92	77.21	76.40	79.63	78.78	79.69	79.18	79.75	80.32	84.30	77.44	79.34
2018	73.38	77.36	78.30	79.14	78.06	78.79	77.45	77.57	78.96	79.02	79.17	73.26

MetS: meteorological station, HLI: heat load index, **cool** (HLI≤70.0), **warm** (between 70.1 and 77.0), hot (between 77.1 and 86.0), and **very hot** (HLI ≥86.0).

Weather conditions of Bida (Niger State) were observed to be cool (HLI ≤ 70.00) more in 3 out of 5 months of the yearly-dry season, while the 2 typical harmattan periods: January and December still had cool weather conditions. The late early-dry season (March) and early late-dry season (November) had indications of both cool (HLI ≤ 70) and warm (HLI between 70.10 and 77.00) weather conditions, respectively (Table 3). The weather conditions of Minna (Niger State) had a cool (HLI ≤ 70.00) indication in three out of the five months of the dry season, while the 2 typical harmattan periods of January and December still had a cool indication. The weather conditions of Markudi (Benue State) and its environs were also cool (HLI ≤ 70.00) in three out of five months of dry periods, while the 2 typical harmattan periods, January and December still had cool indications. Both early (March) and late (November) dry periods had warm (HLI between 70.10 and 77.00) indications in the dry periods. There was a hot (HLI between 77.1 and 86.00) indication for 9 years in March and 6 years in November, respectively (Table 5), which the climate change effects might influence. Both 2009 and 2011 were warm years for having HLI between 70.10 and 77.00. However, the wet periods (April to October) had warm (HLI between 70.10 and 77.00) and hot (HLI between 77.1 and 86.00) indications (Table 4). No trace of a very hot (HLI ≥ 86.0) indication was observed, so it is possible to infer that the climate change effects in Markudi (Benue State) and its environs were minimal. A reliability test was conducted before comparing the average HLI of the heat loads across the five locations and their environments.

The result showed that the 12-month data over the past 32 years of study had a Cronbach's value of 0.899 and indicated a good internal consistency among the combined climatic variables that computed the HLI. The Hotelling's *t*-squared statistic (t^2) of the test of differences among the multivariate means of different populations (i.e., the five study locations and their environs) indicated a highly significant (F = 55.058, p = 0.000) data distribution. The monthly compared average of the HLI (N=32, 1987-2018) showed that weather conditions in Benin, Ondo and their environs were hot (HLI between 77.10 and 86.00) for 11 months except in January when it was warm (HLI between 70.10 and 77.00). Bida, Minna, Makurdi and their environs indicated that their rainy periods (April to October) had hot weather conditions, though April was warm (HLI between 70.10 and 77.00) in Minna; the three locations were cool across Jan., Feb. and Dec. with HLI ≤ 70.00, showing that the harmattan periods peculiar to them still prevailed.

Table 3: Computed HLI for Bida Mets (Niger State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	68.23	74.55	76.56	77.17	76.99	80.14	79.96	80.22	80.17	78.21	69.77	64.57
1988	69.47	67.97	77.20	80.78	83.80	80.24	80.39	80.25	80.84	78.59	71.33	64.60
1989	55.05	59.55	75.06	79.22	81.41	79.88	78.99	80.99	80.75	79.00	72.19	65.96
1990	67.32	65.18	66.90	79.48	80.08	79.21	80.59	81.15	78.72	79.25	76.09	73.68
1991	64.19	74.06	78.55	79.64	82.89	81.75	81.84	80.80	80.23	79.37	73.63	65.45
1992	61.53	64.13	73.80	79.45	78.80	79.61	80.19	79.06	80.19	78.77	70.43	64.24
1993	60.78	69.50	74.73	78.05	79.09	81.65	81.26	79.46	78.56	80.27	77.96	63.89
1994	66.52	65.33	77.37	79.57	81.06	79.07	80.21	81.61	82.95	81.49	72.68	62.41
1995	62.06	67.48	78.44	80.10	81.37	80.13	80.84	83.18	80.68	80.33	72.49	66.33
1996	66.21	73.97	79.57	78.17	79.60	79.85	78.49	79.64	79.85	79.39	67.29	55.83
1997	65.62	59.92	72.43	78.88	80.58	81.20	78.86	78.92	78.86	78.76	73.78	66.88
1998	61.99	68.25	68.35	79.09	79.95	78.86	78.90	78.67	79.44	79.68	72.69	66.44
1999	65.97	68.64	77.88	78.12	78.46	78.77	79.47	79.07	79.81	79.25	73.44	63.78
2000	68.33	59.84	68.90	79.37	79.48	79.76	79.60	79.74	81.02	81.14	73.56	66.30
2001	62.40	63.60	76.61	78.60	80.13	80.79	80.29	79.81	79.76	78.73	71.63	65.92

2002	63.22	68.97	75.58	80.05	74.52	79.24	80.95	81.00	82.00	82.30	72.93	66.81
2003	71.09	74.25	70.63	77.80	75.97	80.25	79.82	80.11	83.33	81.33	73.34	64.70
2004	66.29	58.81	67.07	74.38	79.93	78.59	79.69	81.06	81.79	83.07	74.38	64.40
2005	59.59	74.15	78.87	80.41	80.25	80.75	85.39	84.50	81.37	84.47	70.28	72.37
2006	79.07	79.58	83.96	85.43	85.85	85.99	80.81	80.44	81.33	81.27	67.86	61.22
2007	58.47	68.29	72.39	81.16	79.57	82.56	81.01	81.48	82.02	80.63	78.38	64.46
2008	59.98	60.51	76.45	82.38	83.35	84.33	83.75	82.80	84.42	78.96	71.03	67.81
2009	65.59	76.58	86.06	76.42	78.17	77.53	76.64	78.52	77.54	77.18	67.82	65.61
2010	62.20	68.42	76.65	76.68	76.61	77.25	77.17	77.76	77.51	74.24	70.34	64.07
2011	60.33	72.13	78.38	77.57	80.12	78.75	79.63	79.10	78.68	78.91	68.91	59.16
2012	63.28	70.32	75.42	73.29	74.06	78.24	80.22	80.14	80.09	79.42	73.76	68.12
2013	114.85	68.47	75.96	72.61	73.58	75.50	75.78	76.47	76.69	72.31	67.40	63.47
2014	114.18	67.09	74.68	71.42	73.84	76.41	77.93	76.90	76.11	72.82	67.05	63.06
2015	60.87	69.16	74.42	74.53	76.19	76.32	78.00	76.70	77.26	73.85	64.44	63.10
2016	59.67	65.17	82.14	81.51	81.44	80.46	80.51	81.08	82.23	81.98	74.42	65.13
2017	63.49	67.13	76.32	75.74	75.37	76.89	77.80	77.44	76.88	73.43	67.00	63.46
2018	57.21	72.66	78.38	80.15	78.38	78.67	79.34	79.65	78.85	79.32	73.52	61.86

MetS: meteorological station, HLI: heat load index, **cool** (HLI≤70.0), **warm** (between 70.1 and 77.0), hot (between 77.1 and 86.0), and **very hot** (HLI ≥86.0).

Table 4: Computed HLI for Minna Mets (Niger State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	61.25	65.72	70.31	70.43	77.15	78.66	80.11	78.94	78.84	76.75	66.59	62.76
1988	60.00	62.05	70.46	77.58	77.85	79.50	80.79	79.41	78.26	79.90	67.80	61.21
1989	52.18	55.21	69.80	74.10	78.25	77.33	79.72	81.61	79.62	78.29	65.65	60.86
1990	62.81	59.92	59.65	76.21	78.05	77.53	77.58	79.24	77.58	79.02	73.98	72.96
1991	60.39	74.08	73.54	78.88	79.66	79.13	80.61	81.24	79.73	80.12	70.14	60.59
1992	60.07	68.47	78.89	79.44	79.89	78.43	78.28	76.74	74.72	69.17	62.49	57.97
1993	56.85	64.78	71.11	75.87	76.48	77.02	77.35	77.23	76.89	77.51	72.37	63.37
1994	61.03	59.59	73.79	74.90	79.63	78.17	79.50	77.50	78.46	77.11	66.47	55.31
1995	58.40	59.68	71.07	75.60	76.43	75.28	75.94	76.89	76.18	76.18	64.26	61.59
1996	61.82	66.80	74.29	75.47	74.89	75.70	76.14	77.02	76.80	75.43	61.12	61.67
1997	60.55	63.21	75.55	79.09	78.58	78.39	77.73	77.67	76.72	67.90	63.01	60.33
1998	58.32	62.79	62.73	75.61	77.90	77.77	77.95	78.15	78.37	78.60	69.19	62.71
1999	60.71	66.04	75.75	73.64	75.50	76.42	76.95	77.63	77.76	78.13	70.86	58.78
2000	63.81	56.53	66.01	76.15	77.31	76.07	77.59	77.67	78.24	76.10	66.44	61.40
2001	58.90	61.55	76.61	81.15	80.94	78.77	83.39	83.58	82.61	80.27	72.02	72.52
2002	58.44	65.34	76.60	79.05	79.31	79.92	81.69	81.48	80.11	80.06	68.28	64.76
2003	65.65	69.70	70.72	77.50	78.10	79.61	79.78	77.87	79.69	80.74	71.51	61.67
2004	67.29	66.95	68.22	76.14	78.73	78.46	77.40	80.26	81.08	81.23	71.46	59.96
2005	57.82	70.04	77.06	78.85	79.10	80.88	81.22	80.16	80.80	79.05	71.97	62.56
2006	66.09	72.52	76.49	79.04	81.24	80.89	81.17	81.44	80.82	80.53	72.52	60.30
2007	61.03	66.22	72.40	80.81	81.06	84.83	84.02	84.22	83.58	83.20	67.90	63.01

2008	59.61	60.94	68.94	73.65	76.57	77.13	77.34	77.78	78.18	76.53	66.67	65.29
2009	69.75	70.05	69.34	84.81	83.85	81.77	81.16	81.41	82.06	83.03	75.79	65.46
2010	60.74	62.24	66.97	74.77	74.82	77.04	76.38	79.20	78.91	78.69	70.97	66.07
2011	57.85	67.35	65.23	66.92	72.85	74.56	73.51	74.95	75.96	75.05	65.09	59.08
2012	61.76	67.54	61.97	72.29	74.84	74.94	77.47	79.75	78.62	76.15	70.28	64.61
2013	65.75	65.34	65.51	76.52	80.39	77.34	79.35	80.03	79.85	81.45	75.69	76.19
2014	64.96	74.30	73.88	79.15	81.11	79.71	81.50	81.50	80.42	80.12	69.08	64.14
2015	59.08	74.82	82.56	86.43	85.06	82.19	81.49	78.91	77.71	76.13	66.32	69.86
2016	61.40	67.53	75.18	77.51	78.06	77.83	79.17	79.04	77.87	77.68	71.52	65.42
2017	63.59	61.07	73.25	79.01	77.48	77.99	78.30	78.35	79.11	79.18	68.31	57.88
2018	60.95	63.52	70.20	74.93	75.98	75.53	77.42	77.60	77.03	76.26	65.93	64.55

MetS: meteorological station, HLI: heat load index, **cool** (HLI≤70.0), **warm** (between 70.1 and 77.0), hot (between 77.1 and 86.0), and **very hot** (HLI ≥86.0).

Table 5: Computed HLI for Markudi Mets (Benue State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	65.75	67.65	76.20	78.85	79.63	77.85	80.76	79.35	79.21	79.04	75.08	64.99
1988	61.69	63.25	74.08	71.70	81.72	79.26	78.46	79.66	79.41	79.55	76.79	71.71
1989	67.84	65.64	68.92	76.81	77.90	78.76	78.21	79.06	78.37	78.15	76.95	71.86
1990	62.89	69.84	76.12	80.33	78.63	77.79	76.32	78.40	78.17	78.96	74.63	64.13
1991	61.22	64.68	77.88	77.16	78.78	77.47	77.05	75.67	78.16	79.19	76.04	68.06
1992	62.68	68.26	74.54	75.72	75.54	78.28	78.40	78.79	78.50	78.00	76.07	64.74
1993	63.22	66.98	74.50	77.37	77.88	76.60	74.05	77.86	78.63	80.14	70.13	59.68
1994	59.34	67.65	75.64	76.58	77.97	77.74	76.86	78.86	78.28	78.47	69.74	66.26
1995	67.28	69.09	77.63	75.76	78.42	78.95	77.51	78.14	77.83	79.34	74.65	68.11
1996	64.71	62.45	73.19	78.57	81.54	79.75	77.44	77.94	80.15	79.98	81.00	69.85
1997	66.79	70.69	70.78	76.28	77.36	79.66	78.40	79.58	78.05	78.76	78.83	67.22
1998	66.72	72.03	81.75	76.78	79.41	76.81	80.66	78.43	79.79	80.54	78.21	67.80
1999	66.57	65.65	73.22	78.32	79.86	79.69	79.86	78.94	79.61	79.55	76.67	67.17
2000	64.17	69.00	77.36	78.86	78.71	79.27	78.24	78.98	78.44	76.85	72.37	67.97
2001	67.59	70.19	78.65	80.98	80.04	77.63	78.25	79.09	79.39	79.19	75.91	75.70
2002	70.24	74.34	73.48	78.76	75.32	78.63	78.26	78.48	78.86	79.05	78.40	71.41
2003	65.34	70.64	76.13	82.93	79.95	78.93	79.33	79.75	79.81	79.35	72.79	72.02
2004	66.46	77.12	78.32	79.17	79.30	79.15	79.42	77.62	78.42	77.05	71.09	71.40
2005	74.40	74.08	76.09	74.19	77.68	78.21	78.40	79.03	80.79	78.15	73.39	65.96
2006	61.18	71.19	74.21	80.08	81.04	78.75	78.43	80.19	78.89	79.88	79.48	68.48
2007	63.06	80.80	83.01	84.90	81.15	79.66	77.57	76.73	72.92	72.18	74.58	67.32
2008	68.25	75.09	75.47	80.30	79.10	78.57	78.29	78.56	79.25	79.34	73.17	66.67
2009	64.06	70.34	69.25	74.53	76.32	76.65	76.25	76.82	75.64	76.44	70.77	63.02
2010	65.56	66.58	69.35	74.74	75.86	77.72	78.36	78.63	78.39	78.05	76.19	63.91
2011	62.00	71.25	74.48	74.51	75.83	77.42	75.70	76.97	76.73	76.24	71.51	66.24
2012	68.59	64.66	67.26	77.95	77.62	78.82	78.78	79.00	79.44	76.26	75.89	73.33
2013	64.46	68.26	72.74	74.31	75.82	75.92	78.17	77.90	78.76	77.38	74.67	74.86

2014	66.59	67.14	77.28	74.36	76.93	77.00	76.54	77.43	78.05	78.37	74.38	65.49
2015	61.77	70.12	74.36	77.51	81.23	79.39	77.12	78.77	79.10	81.24	74.51	68.31
2016	54.41	65.57	79.02	79.50	78.00	77.62	76.88	77.57	77.82	77.44	74.51	69.33
2017	67.37	70.50	76.38	78.43	78.69	77.87	79.09	78.93	78.50	80.35	78.24	68.46
2018	64.58	77.81	79.06	80.89	80.00	79.31	78.56	77.61	76.03	76.29	75.32	65.23

MetS: meteorological station, HLI: heat load index, **cool** (HLI≤70.0), **warm** (between 70.1 and 77.0), hot (between 77.1 and 86.0), and **very hot** (HLI ≥86.0).

In addition, March indicated a warm while Nov. indicated a hot weather condition except in Minna, where it was cool (Table 6).

The similarity of occurrences of heat load as stress influenced by climate variability or change effects within the 12 months of the past 32 years (1987-2018) was assessed with the correlation matrix analysis, and the results (Pearson's Correlation) showed various associations that existed among the monthly quantified HLI. All the observed associations/ correlations between the months were very strong: April and May (0.861), April and June (0.822), May and June (0.846), September and October (0.801), and November and December (0.867). They were observed to be significant at 0.01 level (Table 7).

The Kaiser-Meyer-Olkin (KMO) and Bartlett's tests that were performed before the computed HLI values were subjected to the factor analysis for the Principal Component Analysis (PCA) showed that the 32-year data of the three climate elements adopted to calculate the HLI were meritorious (KMO = 0.898) and valuable ($\chi 2$ = 1844.136, $p < 0.05$) (Table 8). The PCA showed that the entire year except for August (i.e., the dry-break period) was classified under Component 1 as having a high eigenvector with eigenvalue (greater than 0.8 except for four months: January, July, September, and October) and accounting for nearly 61.00 % of the variance, while August is under the Component 2 having high eigenvector with eigenvalue of 0.805 and nearly 14.00 % of variance. Thus, eleven months out of the entire 12 months of a year indicated climate change effects throughout the assessed 32 years.

DISCUSSION

Aside from computing the heat load index over the past 32 years for each month, yearly average values were compared of the five study stations and their environs. The likeliness in the climate variability or change effects through the heat loads among the months over the past 32 years (1987-2018) under study had been assessed through Pearson's Correlation; this was further verified, established and detailed with the Principal Components Analysis with the associated % variance. The dry period typifies with harmattan in Nigeria could not be confirmed in January and December, because the cool weather values and conditions were exceeded in Benin, Ondo and their environs. The non-occurrences of harmattan indications, which were supposed to be cool, might indicate climate change effects. Thus, the prevailing weather conditions within the studied 32 years indicated a hot heat load in both locations. Deviation from the weather conditions in Bida (Niger State) and its environs occurred in Jan. 2006 and Nov. 2007, when the weather conditions were hot, as well as in January 2013 and 2014, when the weather conditions were very hot, making the wet periods (April to October) indicated warm and hot weather conditions. For the Minna and its environs, the late early-dry period (March) and early late-dry period

(November) indicated both cool and warm weather conditions. The early wet period indicated a very hot weather condition in 2015. For the Makurdi and its environs, wet periods (April to October) had warm and hot indications of climate change effects.

Table 6: Comparison of the Monthly Computed HLI across the Five Locations

Reliability Statistics			Hotelling's T-Squared Test				
Cronbach's Alpha	Cronbach's Alpha Based on Standardised Items	N of Items	Hotelling's T-Squared	F	df1	df2	Sig
0.899	0.940	12	646.284	55.058	11	149	0.000

	Descriptive Statistics (N = 32, 1987-2018)					ANOVA	
	Benin	Ondo	Bida	Minna	Markudi	F	Sig.
JAN	76.90±5.07	76.50±4.91	67.03±13.27	61.21±3.44	64.90±3.60	31.854	0.000
FEB	80.26±4.64	78.41±3.97	68.24±5.24	65.37±4.93	69.64±4.25	64.366	0.000
MAR	82.06±2.99	80.81±3.52	75.80±4.37	71.38±5.15	75.20±3.57	38.329	0.000
APR	82.02±2.81	81.86±2.59	78.35±2.92	76.92±3.76	77.72±2.80	20.364	0.000
MAY	82.12±2.27	82.23±3.13	79.09±2.99	78.35±2.62	78.54±1.83	17.738	0.000
JUN	81.79±1.85	81.82±2.09	79.64±2.20	78.27±2.25	78.29±1.03	26.823	0.000
JUL	80.94±1.51	80.33±1.79	79.82±1.87	79.00±2.32	77.99±1.38	13.102	0.000
AUG	80.17±1.45	79.59±1.99	79.93±1.82	79.20±2.08	78.40±0.99	5.266	0.001
SEPT	81.34±1.40	81.44±2.19	80.00±2.02	78.83±1.98	78.42±1.47	18.305	0.000
OCT	81.67±1.98	82.06±2.80	78.99±2.91	77.99±3.27	78.40±1.75	17.063	0.000
NOV	81.59±2.53	82.22±3.94	71.62±3.25	68.80±3.68	75.06±2.75	105.861	0.000
DEC	78.98±3.41	80.10±3.91	64.85±3.25	63.28±4.52	68.02±3.51	144.007	0.000

MetS: meteorological station, HLI: heat load index: **cool** (HLI≤70.0), **warm** (between 70.1 and 77.0), hot (between 77.1 and 86.0), and **very hot** (HLI ≥86.0).

Table 7: Pearson's Correlations of the Computed HLI across the Study Locations

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
Feb	0.621**										
Mar	0.493**	0.789**									
Apr	0.356**	0.669**	0.726**								
May	0.345**	0.593**	0.675**	0.861**							
Jun	0.440**	0.640**	0.651**	0.822**	0.846**						
Jul	0.226**	0.442**	0.502**	0.660**	0.672**	0.735**					
Aug	0.101	0.232**	0.238**	0.469**	0.498**	0.554**	0.696**				
Sept	0.357**	0.435**	0.438**	0.585**	0.647**	0.709**	0.678**	0.735**			
Oct	0.325**	0.506**	0.410**	0.567**	0.615**	0.661**	0.573**	0.609**	0.801**		
Nov	0.558**	0.703**	0.574**	0.609**	0.612**	0.651**	0.426**	0.278**	0.582**	0.720**	
Dec	0.604**	0.704**	0.583**	0.597**	0.585**	0.602**	0.429**	0.252**	0.534**	0.610**	0.867**

**.Correlation was significant at 0.01 level (2-tailed) of significance, HLI: heat load index

Table 8: Principal Component Analysis for the Computed HLI

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.898
Bartlett's Test of Sphericity	Approx. Chi-Square	1844.136
	Df	66
	Sig.	0.000

	Component	
	1	2
JAN	0.688	-0.368
FEB	0.873	-0.207
MAR	0.818	-0.097
APR	0.823	0.254
MAY	0.805	0.332
JUN	0.836	0.350
JUL	0.617	0.606
AUG	0.400	**0.805**
SEPT	0.675	0.573
OCT	0.707	0.427
NOV	0.868	-0.078
DEC	0.860	-0.145

Extraction Method: Principal Component Analysis.
Rotation Method: Quartimax with Kaiser Normalization.

Initial Eigenvalues		
Total	% of Variance	Cumulative %
7.315	60.959	60.959
1.641	13.675	74.634

HLI: heat load index

Although a national stress standard hardly exists, exposure guidelines based on the HLI would be helpful to assess the prevailing heat loads, which could be unknown with little or no attention without the biometeorological effort like the HLI. The quantitative and qualitative description of climate variability or change effects is the heat load, which best associates the extent (qualitative description) of environment-heat stress on the health of humans and the environment to the adopted and established values (quantitative description). The study, through the calculated heat load index with ranges of values, described how the selected environs had been impacted over the past 32 years (1987-2018).

The likely effects of heat load from the climate variability or change are introducing additional risks to human health and environmental safety, threatening the locations and their neighbourhood, reducing the endowed biodiversity of the areas with shortage of raw materials to the efficacy and scope of medicines, compromising the biodiversity of nutritional food chain values, reducing the qualities of health and lowering life expectancies of the biotic components of the study environment, and destructing the wild spaces thereby facilitating zoonotic diseases' emergence from the climate variability or change (UNEP, 2021).

The computed heat load index across the study locations and their environs informed more of the warming environment considering other climatic elements unlike the temperature alone. Implications of the heat load in humans are that more blood is pumped to the skin, and sweat increases. The biometeorological nexus indicated by the heat loads from the environment on humans is increased water consumption, worsening of the underlying health issues, and increased human discomforts. In turn, the body increases its rate of heat loss to balance the environment-heat burden, i.e., osmoregulates, thereby increasing the body's inner temperature gradually, beyond which various heat illnesses can be influenced and very serious (CCOHS, 2022).

CONCLUSION

The study generally established from the monthly compared average HLI that the wet periods (April to October) had been having hot weather conditions across the five locations and their environs except in April when it was warm at Minna. December to February of the dry periods had been cool in Bida, Niger, Makurdi and their environs. Pearson’s Correlation informed that the combined effects of the three weather parameters that computed HLI were very strong at a 0.01 significant level in the early-wet season (April to June), late-wet season (September and October), and late-dry season (November and December). The Principal Component Analysis indicated eleven months with 61.00 % variance under Component 1, and four months (January, July, September and October) had eigenvalue less than 0.8, while August (i.e., the dry spell period) was indicated under Component 2 with 14.00 % variance and eigenvalue of 0.805.

ACKNOWLEDGEMENTS:

I express a sincere gratitude to the World Bank through its Centre of Agricultural Development and Sustainable Environment (CEADESE) in the Federal University of Agriculture Abeokuta (FUNAAB), Ogun State, for the approved grant for my PhDAgSE research as a 3rd Cohort student [Matriculation Number: PG 09/ 0181] in Environmental Systems and Climate Change programme. The director of CEADESE and my programme leader are highly appreciated. I am indebted to the trio of Olaide Khadijat, Qanita Rooreromi, Yasir Ooreoluwa, and Amrullah Ikeoluwa, whose moral support strengthened my efforts.

REFERENCES

Aharoni, Y., Ravagnolo, O. and Misztal, I. (2002). Comparison of lactational responses of dairy cows in Georgia and Israel to heat load and photoperiod. *Animal Science* 75(3): 469-476.

Battisti, D.S. and Naylor, R.L. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat. *Science* 323: 240–244.

Bernabucci, U., Lacetera, N.L., Baumgard, H., Rhoads, R.P., Ronchi, B. and Nardone, A. (2010). Metabolic and hormonal acclimation to heat stress in domesticated ruminants. *Animal Research*, 4(7): 1167–1183.

Bouraoui, R., Lahmar. M., Majdoub, A., Djemali, M. and Belyea, R. (2002). The relationship of the temperature-humidity index with milk production of dairy cows in a Mediterranean climate. *Animal Research* 51 (6): 479-491.

CCOHS (Canadian Center of Occupational Health and Safety), (2022). Hot Environments - Health Effects and First Aid. https://www.ccohs.ca/oshanswers/phys_agents/heat/heat_health.html#:~:text=In%20a%20very%20hot%20environment,which%20can%20be%20very%20s erious. Fact sheet last revised: 2022-05-25 and modified on 2023-06-13. Accessed on 10-09-2023.

Chuine, I., YoiuTsup, P., Viovy, N., Seguin, B., Daux, V., and Laduire, L. E. (2004). Grape Ripening as a Past Climate Indicator. *Nature* 432: 289–290.

Correa-Calderon, A., Armstrong, D., Ray, D, Denise S, Enns M and Howison C. (2004). Thermoregulatory responses of Holstein and Brown Swiss heat-stressed dairy cows to two different cooling systems. *International Journal of Biometeorology* 48 (3): 142-148.

Eigenberg, R.A., Hahn, G.L., Nienaber, J.A. and Brown-Brandl, T.M. (2003). Development of a New Respiration Rate Monitor for Cattle. *Trans. ASAE* 43: 723–728.

Frimpong, K. (2015). An Appraisal of Experiences of Climate Change and Adaptive Response to Heat Stress by Farmers in Rural Ghana. PhD Thesis, Edith Cowan University, Ghana. Retrieved from http://ro.ecu.edu.au/theses/1653. Accessed on 15 October 2017. 216 pp.

Gaughan JG, Goopy J, Spark J. Excessive heat load index for feedlot cattle. *In: Report of the Meat and Livestock Australia Project.* FLOT, MLA Ltd., Sydney: (2002). p. 316.

Gaughan, J.G., Mader, T.L., Holt, S.M. and Lisle, A. (2008). A New Heat Load Index for Feedlot Cattle. *Journal of Animal Science* 86: 226–234.

Hulme, P.H. (2005). Adapting to Climate Change: Is There Scope for Ecological Management in the Face of a Global Threat? *Journal of Applied Ecology* 42 (5): 784-794.

Ingram, D.L., and Mount, L.E. (1975). Heat Exchange between Animal and Environment. In: Man and Animals in Hot Environments. *Topics in Environmental Physiology and Medicine*. Springer, New York, NY. https://doi.org/10.1007/978-1-4613-9368-9_2.

Kjellstrom, T. (2009). Climate Change, Direct Heat Exposure, Health and Well-Being in Low and Middle-income Countries. *Global Health Action* 2: 10.3402/gha.v2i0.1958.

Le Roy Ladurie, E. (2004). *Histoire Humaine et Comparee du Climat.* Paris: Fayard. *In*: Poumadere, M., Mays, C., Le Mer, S. and Blong, R. The 2003 Heatwave in France: Dangerous Climate Change Here and Now. *Society for Risk Analysis* 25 (6): 1483- 1494. DOI: 10.1111/j.1539-6924.2005.00694.x.

Mader, T.L. and Davis, M.S. (2002). Wind Speed and Solar Radiation Corrections for the Temperature-humidity Index. *In Proceedings of the 15th Conference on Biometeorology and Aerobiology Joint with 16th International Congress on Biometeorology*, Kansas City, MO, USA, 27 October, pp. 10–28.

Mader, T.L., Davis, M.S. and Brown-Brandl, T. (2006). Environmental Factors Influencing Heat Stress in Feedlot Cattle. *Journal of Dairy Science* 84 (3): 712-719.

Martin, S.L., Cakmak, S., Hebbern, C.A., Avramescu, M.L. and Tremblay, N. (2011). Climate Change and Future Temperature-related Mortality in 15

Canadian Cities. *International Journal of Biometeorology,* 56: 605–619.

Mekis, E., Vincent, L.A., Shephard, M.W. and Zhang, X. (2015). Trends in Severe Weather Conditions Based on Humidex, Wind Chill, and Heavy Rainfall Events in Canada for 1953–2012. *Atmos. Ocean* 53 (4):383–397. DOI:10.1080/07055900.2015.1086970

NCDC (National Climatic Data Center-National Center for Environmental Information (NOAA), (2020). Available online: www. ncdc.noaa.gov (accessed on 11 December 2020).

NOAA (2002). National Weather Service Hydrometeorological Prediction Center. Mean Heat Index Forecasts. NOAA, Silver Spring, Md. (http://www.hpc.ncep.noaa.gov/heat–index. html). *In: Jiang, C., Shaw, K.S., Upperman, C.R., Blythe, D., Mitchell, C., Murtugudde, R., Sapkota, A.R. and Sapkota, A. 2015.* Climate change, extreme events and increased risk of salmonellosis in Maryland, USA: Evidence for Coastal Vulnerability. *Environment International* 83: 58–62.

Oechsli, F.W. and Buechley, R.W. (1970). Excess Mortality Associated with Three Los Angeles September hot spells. *Environmental Research* 3: 277–284.

Parsons, K. (2003). Human Thermal Environment. The Effect of Hot, Moderate and Cold Temperatures on Human Health, Comfort and Performance New York: CRC Press.

Pradhan, B., Shrestha, S., Shrestha, R., Pradhanang, S., Kayastha, B. and Pradhan, P. (2013). Assessing Climate Change and Heat Stress Responses in the Tarai Region of Nepal. *Industrial Health* 51 (1): 101-112. http://dx.doi.org/10.2486/indhealth.2012-0166.

Scholtz, M.M., Mc Manus, C., Leeuw, K.J., Louvandini, H., Seixas, L., de Melo, C.B., Theunissen, A. and Neser, F.W.C. (2013). The Effect of Global Warming on Beef Production in Developing Countries of the Southern Hemisphere. *Natural Science.* 5: 106-119.

Seneviratne, S.I., Donat, M.G., Mueller, B., and Alexander, L.V. (2014). No Pause in the Increase of Hot Temperature Extremes. *Nature Climate Change* 4: 161 – 163.

Silva, R.G., Morais, D.A. and Guilhermino, M.M. (2007). Evaluation of Thermal Stress Indices for Dairy Cows in Tropical Regions. *Revista Brasileira de Zootecnia* 36: 1192–1198.

Sippel, S. and Otto, F.E.L. (2014). Beyond Climatological Extremes - Assessing How the Odds of Hydrometeorological Extreme Events in South-East Europe Change in a Warming Climate. *Climate Change* 125: 381–398.

Spiers, D.E., Spain, J.N., Sampson, J.D. and Rhoads, R.P. (2004). Use of Physiological Parameters to Predict Milk Yield and Feed Intake in Heat-stressed Dairy Cows. *Journal of Thermal Biology* 29 (7-8): 759-764.

Steadman R.G. (1994). Norms of Apparent Temperature in Australia. *Australian Meteorological Magazine* 43: 1–16.

UNDP (United Nations Development Programme), (2020). https://www.undp.org/content/ dam/undp/library/corporate/brochure/S

DGs_Booklet_Web_En.pdf. Accessed on 23 January 2020.

UNEP (United Nations Environment Program), (2021). Six reasons why a healthy environment should be a human right. Environmental rights and governance. Story. https://www.unep.org/news-and-stories/story/six-reasons-why-healthy-environment-should-be-human-right available online on 13-04-2021. Accessed on 10-09-2023.

West, J.W. (2003). Effects of Heat-stress on Production in Dairy Cattle. *Journal of Dairy Science* 86: 2131–2144.

Wilhelmi, O.V., Purvis, K.L. and Harriss. R.C. (2004). Designing a Geospatial Information Infrastructure for Mitigation of Heatwave Hazards in Urban Areas. *Natural Hazards Review* 5 (3): 147-168.

Willett, K.M. and Sherwood, S. (2012). Using the Wet-Bulb Globe Temperature, exceedance of Heat Index Thresholds for 15 Regions under a Warming Climate. *International Journal of Climatology* 32: 161–177.