JOURNAL OF METEOROLOGY AND CLIMATE SCIENCE
J. Met & Clim. Sci. 22(1): 33-53 (June, 2023)

CLIMATE VARIABILITY ENVIRONMENTAL STRESS INDICATION ACROSS FOUR RAIN-FED STATES IN NIGERIA USING MULTIVARIATE ANALYSIS

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Abstract

Climate parameters can be used to verify already established model for climate variability or change indication (CCI) of environmental stress (ESI) to ensure agricultural productivity and sustainability. The study verified ESI from 32-year temperature, relative humidity and solar radiation data across four (Benue, Edo, Niger and Ondo) States in Nigeria using multiple regression model. The ESI was higher than 30 from February to April 2005 and May 2007 in Edo, April 2006, January 2013 and 2014 in Bida. The reliability statistics had a Cronbach's value of 0.821, so the data had good internal consistency. The data distributions were highly significant ($F = 87.355$, $p = 0.000$) from the Hotelling's *t*-squared statistic (t^2). There was a very strong correlation (0.814) between April and May at 0.01 levels. The model explained 64.2 % variance in the variables. The Durbin-Watson value < 2 indicated positive autocorrelation. The ANOVA indicated a general significance ($p < 0.05$) in the model's fitness. The computed ESI was meritorious (KMO = 0.859) and valuable ($\chi 2 = 1494.061$, $p < 0.05$) for the factor analysis. The Principal Component Analysis showed that the seven-month rainy periods under Component 1 with higher eigenvalues had been having higher ESI than the dry periods under Component 2. The four study States could be having shortage rainfall distribution and the farmers could easily be getting tired thereby being less productive from ESI. So, there is need for the farmers across the four States to craft strategies for proper adaptation to effects of the climate variability and change.

Keywords: agroecological zone, farmers' adaptation, rainfall distribution, heat indices, multiple regression model.

INTRODUCTION

Over few decades, there has been a rise in atmospheric temperature across West Africa (New *et al.,* 2006); this corroborated the IPCC predictions that sub-Saharan Africa is expected to reach sustained warming above the typical global projection. The poorest countries in the region would be most vulnerable to the impacts of such warming (Haines *et al.,* 2006). This uneven increase in the mean temperatures throughout the African region is being confirmed (Collins, 2011). International agencies now design frameworks on climate change (CC) from the observed indications and assessed models to influence a regional strategy and protect the environment from CC impacts (WHO, 2012). Though, various agroecological zones tolerate environmental stress or extreme heat above the expected limits, albeit for short periods (Kenney *et al.,* 2004), there is little literature on the effects of CC unevenness and extreme heat events on food systems and production (Thorton *et al.,* 2014). The CC impacts were previously poorly understood with minimal studies in tropical countries (Kjellstrom and McMichael, 2013).

Research on CC and its physiological health effects were once limited in the developing world (Kjellstrom, 2009), unlike in the developed world (Ebi *et al.,* 2006). The CC and sustainable development establish an association between issues concerning health, food security, employment, income and livelihood (Lundgren *et al.,* 2013). A study observed that the plant growers did not adopt a strategy (as a preventive health measure) of resting when tired to avoid associated health effects (Frimpong, 2015). They worked under extreme heat exposure with slight cooling systems, probably the tree shades and breeze from the environmental conditions peculiar to their regions (Frimpong *et al.*, 2012). The dangerous nature of job-related environmental stress is yet to attract adequate research, funding and policy attention from local governments and international bodies (Kjellstrom, 2012). However, developed environmental stress indices ought to be assessed to affirm the factors that emphasise crops susceptibility, human experiences and adaptation to CC effects, environmental stress and heat extreme (Barrett *et al.*, 2015).

Among the indices that can be used to assess the combined effects of climatological parameters for CC indications or effects are the environmental stress index (ESI) and wet-bulb globe temperature (WGBT). The ESI is a substitute for the WGBT (Moran *et al.*, 2011). The WGBT is hard to be adopted for many regions, but ESI was found to be highly correlated with WBGT ($R^2 \geq 0.981$) even for hot-wet and hot-dry climatic conditions (Epstein and Moran, 2006).

Indication of the index heavily depends on human activities (Ethan *et al.*, 2018). As an indication instrument, the index shows people's heat exposure level. So, human work and resting relationships can be regulated to avoid heat-related injuries (USACHPPM, 2003). Heat exposure above the range 33 and 36 °C indicates possible heat-related illnesses on human (such as plant grower) as there would be amplified metabolic heat loads from heavy work performance (Maté and Oosthuizen, 2011). Environmental stress limits human tolerance over time and subjects a person to heat illness without cooling effects (Pal and Eltahir, 2015; Im *et al.*, 2017). The climate change (CC) research at continental (Pascual *et al.*, 2006) and local

(Fosu-Mensah *et al.*, 2012; Appiah, 2014) levels considered CC effects on plant growers using 50-year data of temperature and relative humidity from three stations (Frimpong *et al.*, 2011). More climate data (temperature: T °C, relative humidity: RH %, and solar radiation: SR wm^{-2}) combined for ESI and WBGT computation to assess environmental stress was adopted in this study to calculate ESI across four States in Nigeria using 32-year (1987 to 2018) data.

MATERIALS AND METHODS

Study areas

Four (Benue, Edo, Niger and Ondo) States were chosen across Nigeria. The States were randomly selected for being among the highest crop yieiding States in each of the agroecological zones, considering some sustainable development goals (SDGs) of the UNDP (2020). SDG 2: Zero Hunger to promote sustainable agriculture and achieve improved nutrition with food security. SDG 13: Climate Action to take urgent actions to combat climate change and its impacts. Benue and Niger States are in the derived savannah zones, while Edo and Ondo States are in the forest-humid agroecological zones. The states practise rain-fed agriculture, which climate change can affect.

Climate data acquisition

The study team acquired 32-year (1987-2018) monthly data (temperature: T °C, relative humidity: RH %, and solar radiation: SR wm^{-2}) of the four (Benue, Edo, Niger and Ondo) States from the Nigeria Meteorological Agency (NiMet) in Abuja, Nigeria. The meteorological station (MetS) of each (Benue, Edo, Niger and Ondo) State from where the data were gathered by the NiMet was Makurdi, Benin, Bida & Minna, and Ondo MetS respectively.

Data Handling and Statistical Analysis

Data Pruning

The acquired climatological data were entered in the EXCEL spreadsheet for pruning to ascertain the data were in the same decimal places and avoid bias using TRUC Function

$$= TRUN(number, [digits])$$

The *number* is the value to be pruned; this specifies a number or a cell reference, while *digits* are optional, specifying the number of decimal places to be retained after pruning. If the argument is blank, EXCEL prunes everything after the decimal point.

Determination of the climate change indication: environmental stress index (ESI)

$$ESI = 0.63Ta - 0.03RH + 0.002SR + 0.0054Ta \times RH - 0.073(0.1 + SR)^{-1} \quad - (1)$$

Ta: ambient temperature, RH: relative humidity, and SR: solar radiation [15].

Multivariate analyses

The pruned data were subjected to descriptive (average from monthly values over the 32-year) and Inferential (ANOVA and DMRT) statistics using IBM SPSS v23. Computation for multivariate analyses (Reliability test, Pearson's Correlation, Multiple Regression and Principal Component Analysis) were also performed. The data in the EXCEL document were exported to the SPSS data editor for analysis. Reliability analysis was done after ascertaining that the data types were numeric. Analyse bar was clicked to pick a scale and then reliability analysis. All the data were transferred to the item portion. Setting the model at alpha statistics was chosen to select (1) descriptive for the item, (2) summarises for means and (3) ANOVA table for the F test. Continue was clicked and followed by OK.

Hotelling's t-squared was used for having **several advantages** over the t-test: (1) The Type I error rate is well controlled, (2) The relationship between multiple variables is considered, and (3) It can generate an overall conclusion even if multiple (single) t-tests are inconsistent. While a t-test will inform which variable differs between groups, Hotelling summarises the between-group differences. Bartlett's test was adopted for the factorial analysis to check for the set hypothesis. The **test hypothesis** was that the samples were from populations with (1) the same multivariate mean (**Null hypothesis,** H_0) and (2) different multivariate means (**Alternate hypothesis,** H_1). **Three significant assumptions** were: the samples are (1) independent and have (2) underlying normal distributions and (3) equal variance-covariance matrices (for a 2-sample test).

RESULTS AND DISCUSSION

The environmental heat stress (ESI) computation considers the combined influence of Ta, RH, and SR [15]. The obtained results for the four States are in Tables 1 to 5. High values of ESI above 30 ˚C were observed in 2005 and 2007 out of the 32-year estimations in Benin (Edo State) meteorological station (MetS), from February to April in 2005 and February to May in 2007. None of the months in Ondo MetS indicated ESI beyond 30. The ESI was higher than 30 ˚C in April 2006 and highly extreme (≈ 46) in January 2013 and 2014 in Bida MetS (Niger State). The ESI in Minna (Niger State) and Markudi (Benue State) MetS was less than 30 ˚C.

For the multivariate analysis of the computed ESI (Table 6), the reliability statistics had a Cronbach's value of 0.821, indicating that the internal consistency of the variables was good for the 12 months in the past 32 years. The Hotelling's t-squared statistic (t^2) of the differences between the means of different populations (the five meteorological stations under study) indicated that distributions of the variables were highly significant ($F = 87.355$, $p = 0.000$) (Table 6). The comparative monthly average of the ESI (N=32, 1987-2018) showed that Benin MetS had the highest ESI value throughout the 12 months over the past 32 years. The

MANOVA indicated that the monthly ESI of the five MetS under study differed significantly ($p < 0.05$) (Table 6).

There was an indication from Pearson's correlation analysis (Table 7) that February had a moderate ESI correlation with November (0.595) at 0.05 level and

Mets: Meteorological station

(0.776) at 0.05 and 0.01 levels, and a strong ESI correlation (0.793) between the two late dry periods: November and December at 0.05 and 0.01 levels. The multiple regression model had an adjusted R-squared of 0.612 with an R-squared of 0.642, implying that the model explained 64.2 % variance in the data

December (0.585) 0.01 level. There was a very strong ESI correlation (0.814) between April and May at 0.05 and 0.01 levels, and a strong ESI correlation between August (the dry-break) and two preceding months: June (0.709) and July

(Table 8). The Durbin-Watson value of 0.678 < 2 showed a positive autocorrelation to imply a similarity in the influence of environmental stress from the computed ESI at every MetS under study. The MANOVA indicated a general significance ($p < 0.05$) in the model's fitness.

Table 1 - Computed ESI for Benin MetS (Edo State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	25.87	27.04	26.40	26.96	26.41	25.78	25.31	24.98	25.31	25.54	26.34	25.66
1988	25.63	27.89	26.21	27.13	26.50	25.64	25.10	25.20	25.24	25.89	26.91	24.78
1989	21.15	24.15	26.34	26.67	26.04	25.54	24.83	24.60	24.90	25.58	26.55	25.16
1990	26.29	25.62	27.40	26.67	26.24	25.66	24.74	24.78	25.01	25.28	26.39	26.33
1991	24.98	28.22	27.22	25.95	26.49	26.56	25.03	24.93	25.16	24.77	26.44	24.52
1992	22.34	25.86	27.10	26.96	26.61	25.11	24.30	23.98	24.67	25.23	24.42	24.98
1993	22.50	26.14	25.86	26.48	26.22	25.54	24.46	24.97	25.36	25.65	26.47	24.49
1994	24.25	26.12	27.22	26.69	26.15	25.63	24.94	24.87	25.54	25.34	25.59	22.76
1995	24.62	26.86	26.91	27.29	26.44	25.87	25.40	25.49	25.80	25.34	25.73	25.74
1996	26.99	27.50	27.45	26.76	26.64	26.22	25.20	25.09	25.10	25.75	26.04	27.05
1997	26.02	24.43	26.50	26.20	26.14	25.83	24.73	24.89	25.56	25.75	26.69	25.97
1998	23.39	27.40	27.73	28.08	27.49	26.07	25.45	24.72	25.16	25.87	26.08	25.35
1999	24.98	26.88	27.15	26.50	26.34	25.95	25.09	24.90	25.11	25.24	26.51	25.20
2000	26.07	24.07	26.76	26.84	26.35	25.29	25.25	24.57	25.21	25.63	26.79	24.68
2001	25.36	25.76	27.09	26.03	26.36	25.94	25.27	24.74	25.01	25.87	26.91	27.11
2002	23.75	25.92	27.68	26.81	26.68	25.57	25.61	25.15	25.47	25.50	26.60	24.59
2003	25.95	27.76	27.43	26.88	26.79	25.67	25.14	25.25	25.32	26.15	26.59	25.06
2004	25.56	25.92	27.11	26.49	26.37	25.45	25.26	24.77	25.30	25.80	26.36	27.00
2005	24.34	**30.69**	**32.14**	**30.85**	28.70	27.42	27.01	25.47	26.98	26.49	26.36	25.50
2006	27.68	27.92	26.92	27.62	25.90	25.99	25.53	24.91	24.99	25.96	25.96	25.23
2007	23.88	**31.27**	**31.41**	**32.46**	**31.13**	28.41	26.37	26.14	25.99	27.43	26.51	22.11
2008	20.85	21.90	24.84	24.74	25.16	24.74	24.55	23.65	24.62	24.27	24.73	23.60
2009	26.74	27.70	28.08	26.84	26.41	26.58	26.28	25.50	26.37	25.87	27.18	28.05
2010	28.79	29.57	29.50	28.30	28.09	27.21	26.09	25.69	26.14	26.91	27.52	27.24
2011	22.31	25.47	26.33	25.88	26.02	25.66	24.87	24.72	25.10	25.14	25.42	23.58
2012	23.09	25.83	26.24	25.98	26.38	25.05	24.88	24.51	25.34	25.28	26.00	25.81
2013	25.24	26.22	27.03	26.55	26.32	25.42	24.85	24.56	25.13	25.62	26.00	24.71
2014	26.94	27.10	27.18	27.03	26.93	26.52	25.65	24.88	25.38	26.07	26.79	27.05
2015	24.92	26.17	26.41	27.54	26.81	25.99	25.49	24.75	25.29	26.02	23.28	25.03
2016	26.40	29.66	28.40	28.95	28.03	26.60	26.43	25.64	26.11	27.13	28.02	26.80
2017	25.26	25.82	26.71	26.30	26.44	26.06	25.22	24.97	25.28	25.82	26.23	25.47
2018	27.65	28.95	28.03	27.66	27.01	27.36	26.11	25.98	26.57	27.32	28.39	28.11

ESI: environmental stress index,
MetS: meteorological station, and
The values are compared with the ambient environmental condition of 30 ˚C.

Table 2 - Computed ESI for Ondo MetS (Ondo State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	24.92	26.40	25.94	26.32	25.83	24.58	24.57	24.73	24.60	25.07	25.90	23.93
1988	23.14	25.88	26.02	25.84	25.56	24.24	23.67	23.17	24.31	24.91	25.84	23.72
1989	20.22	22.76	25.77	25.71	25.19	24.39	23.91	23.56	23.91	24.79	26.14	24.52
1990	25.52	24.50	26.60	25.87	25.34	24.96	23.99	23.45	23.91	24.55	25.63	25.27
1991	24.15	26.20	26.19	24.89	25.34	24.81	24.14	23.44	23.96	23.84	25.24	23.50
1992	20.85	24.32	26.10	26.18	25.50	23.99	23.81	23.05	23.43	24.53	23.86	24.39
1993	21.60	26.07	24.83	26.00	25.46	24.71	23.77	23.75	23.95	24.50	24.65	23.96
1994	22.53	24.12	25.07	24.87	24.47	23.77	23.79	22.95	23.95	22.63	22.32	23.44
1995	22.38	25.47	25.79	25.91	25.33	24.75	24.04	24.33	24.13	24.67	24.49	24.90
1996	26.00	26.36	25.86	25.42	25.26	24.81	23.76	23.69	23.83	24.50	24.49	25.93
1997	24.85	22.56	26.05	25.27	25.33	25.06	23.65	23.79	24.66	25.13	25.90	24.98
1998	22.95	25.74	27.98	27.45	26.67	25.06	24.47	23.72	24.14	25.08	26.22	24.45
1999	24.68	25.64	26.49	25.32	25.30	25.12	24.13	23.12	23.71	23.97	25.22	24.10
2000	24.97	22.22	25.68	25.79	25.50	24.55	23.98	23.50	24.50	24.83	25.83	23.96
2001	23.91	24.09	26.08	26.63	25.51	24.64	24.35	23.26	23.81	25.02	25.58	25.87
2002	22.40	25.10	26.82	25.66	25.49	24.80	24.54	23.67	24.17	24.24	25.15	23.60
2003	24.38	26.81	26.53	25.95	25.69	24.64	23.76	23.80	24.35	25.23	25.35	24.40
2004	24.67	24.94	25.79	25.66	25.38	24.47	23.89	23.95	24.31	25.06	25.74	26.28
2005	22.09	26.74	26.56	26.39	26.01	25.23	24.52	23.36	24.59	25.16	26.35	25.90
2006	25.88	27.00	26.37	26.81	25.78	25.37	24.90	24.02	24.52	25.08	26.15	24.21
2007	21.03	24.32	26.09	26.13	25.16	23.98	24.13	22.92	23.86	24.65	25.59	23.79
2008	19.98	20.57	23.52	23.68	23.55	23.87	23.49	23.56	23.91	23.61	23.64	22.80
2009	22.26	23.96	24.27	24.12	24.38	24.26	24.22	24.24	25.14	24.94	24.64	26.73
2010	26.13	27.14	26.35	26.56	26.56	26.09	25.17	24.49	24.69	25.15	24.56	24.41
2011	22.38	25.48	26.07	25.51	25.71	25.21	24.17	24.12	24.75	24.56	24.95	22.51
2012	22.97	25.12	26.57	26.81	25.80	25.29	24.80	23.77	24.65	24.99	25.90	24.10
2013	24.61	25.42	25.66	25.85	25.66	25.36	23.99	24.05	24.34	25.18	25.90	24.67
2014	23.56	25.10	26.07	26.23	25.95	25.81	24.77	23.47	23.96	24.58	25.09	25.33
2015	23.09	26.58	27.21	27.00	26.55	25.19	25.17	24.53	24.69	25.17	26.71	24.83
2016	20.78	23.05	25.15	25.55	25.04	24.97	25.03	23.74	23.73	24.11	24.17	23.37
2017	23.56	24.81	24.80	25.58	25.33	24.92	24.94	24.10	24.06	25.00	24.44	24.51
2018	22.42	25.39	25.50	25.47	24.53	24.45	23.86	23.66	24.37	24.52	25.22	23.06

ESI: environmental stress index,
MetS: meteorological station, and
The values are compared with the ambient environmental condition of 30 ˚C.

Table 3 - Computed ESI for Bida MetS (Niger State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	21.71	25.18	25.94	25.88	26.02	26.01	24.78	25.18	24.80	24.90	21.81	20.36
1988	22.70	22.90	26.83	28.45	29.03	26.28	25.94	25.45	25.11	25.34	23.06	20.89
1989	17.86	20.30	25.86	27.12	26.87	25.39	24.97	24.75	25.28	25.36	23.33	20.68
1990	21.31	21.94	23.09	27.40	26.18	25.76	25.41	25.04	24.68	25.38	25.00	24.07
1991	21.00	25.33	27.68	27.46	26.55	26.29	25.32	25.36	25.03	25.38	23.91	21.20
1992	19.95	21.50	25.71	26.90	25.85	25.87	25.20	24.94	25.12	24.88	22.76	20.21
1993	19.23	23.04	25.45	26.34	26.04	25.45	25.23	24.58	24.16	25.69	25.16	20.54
1994	21.49	21.82	26.57	27.84	26.99	25.19	25.25	25.30	25.75	25.96	23.44	20.03
1995	19.83	22.56	27.23	27.40	26.71	25.75	25.46	26.07	25.23	25.51	23.20	20.42
1996	21.11	25.16	27.62	26.94	26.06	25.40	24.65	24.85	25.35	25.40	21.10	14.69
1997	20.65	19.84	24.51	26.46	26.48	25.61	24.28	24.07	24.71	24.94	23.38	21.04
1998	19.82	23.05	23.47	27.78	26.53	25.52	25.22	24.47	24.74	24.99	23.14	21.09
1999	21.50	22.97	26.97	26.56	25.67	25.49	24.88	24.46	24.32	24.82	23.36	20.17
2000	22.29	19.55	23.57	27.45	26.88	25.40	24.78	24.60	25.19	25.68	23.34	20.97
2001	19.89	20.58	26.09	26.59	26.64	26.36	25.46	25.17	24.77	25.34	23.36	21.35
2002	20.73	23.48	25.48	27.44	24.19	25.58	25.51	25.42	26.14	26.49	23.15	21.76
2003	23.77	25.40	23.89	26.28	24.28	25.47	25.36	25.12	27.10	26.59	23.20	20.63
2004	21.64	19.18	22.75	24.67	26.05	24.91	25.00	26.07	26.63	27.62	24.09	20.21
2005	19.34	25.89	27.84	27.97	27.10	26.34	28.78	26.96	26.00	27.02	23.80	23.21
2006	26.44	27.50	29.01	**30.09**	28.54	28.14	26.17	25.27	25.67	26.42	22.10	19.62
2007	18.90	22.94	24.73	27.58	26.07	26.21	25.29	25.04	25.33	25.03	25.13	20.61
2008	19.10	19.93	25.41	27.55	27.66	27.02	26.22	25.50	26.18	24.87	23.04	21.76
2009	21.08	25.33	29.82	25.87	25.88	24.87	24.00	23.91	24.13	24.59	21.97	20.89
2010	20.00	22.84	26.14	26.16	25.33	24.67	23.90	24.08	23.99	23.22	22.89	20.63
2011	19.36	23.69	26.85	26.39	26.40	25.29	24.95	24.53	24.41	25.23	22.47	19.13
2012	20.69	23.25	25.95	24.36	23.90	24.76	24.98	24.30	24.58	25.22	23.72	21.48
2013	**46.44**	22.62	26.29	24.41	23.95	23.96	23.75	23.71	24.20	23.24	21.89	20.40
2014	**46.37**	22.78	25.89	24.17	24.26	24.81	25.10	24.25	23.99	23.18	21.72	20.01
2015	19.71	23.62	25.62	25.64	25.92	24.88	24.97	24.20	24.39	23.61	21.61	19.56
2016	18.74	21.56	28.30	28.29	27.06	25.77	25.62	25.56	25.96	26.46	24.46	21.19
2017	20.55	22.04	26.11	25.88	24.83	24.86	24.89	24.22	24.09	23.63	21.75	20.58
2018	18.25	24.96	27.47	28.13	26.29	25.89	25.42	25.18	24.93	25.62	24.05	20.02

ESI: environmental stress index,
MetS: meteorological station, and
The values are compared with the ambient environmental condition of 30 ˚C.

Table 4 - Computed ESI for Minna MetS (Niger State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	20.17	22.36	24.05	24.24	26.66	25.38	25.72	24.67	24.67	23.93	20.92	20.29
1988	19.86	21.25	24.03	26.93	26.16	25.50	25.16	23.72	23.35	23.60	21.76	19.51
1989	17.60	19.02	23.44	25.38	25.09	24.37	24.41	24.44	23.30	23.90	21.36	20.13
1990	20.76	20.57	20.86	26.01	25.13	25.38	24.23	24.73	24.25	25.14	23.37	23.44
1991	20.27	24.87	25.17	26.58	25.55	25.52	24.85	24.75	24.34	24.51	22.23	19.95
1992	19.90	23.93	27.42	26.99	26.63	25.06	24.51	23.77	23.33	22.16	20.68	19.42
1993	19.14	22.18	24.60	26.92	26.30	24.93	24.35	24.07	24.11	24.69	22.94	21.15
1994	20.44	20.77	25.88	26.32	25.83	24.76	24.56	24.05	24.43	24.11	21.27	18.59
1995	19.39	20.64	24.95	26.53	25.37	24.58	24.19	23.97	24.11	24.34	21.09	19.94
1996	20.45	22.77	26.06	26.62	25.18	24.26	23.87	23.56	24.05	23.62	19.76	19.91
1997	20.44	22.40	26.48	27.40	25.73	25.25	24.51	24.64	24.30	21.73	19.90	19.70
1998	19.72	22.06	22.44	27.08	26.43	25.25	24.74	24.12	24.50	25.01	22.41	20.75
1999	20.44	22.30	26.70	25.89	25.79	24.95	24.27	23.99	24.15	24.64	22.84	19.69
2000	21.79	19.75	23.28	27.26	27.13	24.13	24.53	24.06	24.67	23.99	21.34	20.34
2001	19.14	20.17	25.52	26.68	26.07	24.60	24.14	23.85	23.52	23.81	21.60	21.85
2002	18.31	20.85	25.63	26.52	26.60	24.79	24.98	24.62	24.10	24.46	21.66	19.98
2003	21.03	23.63	24.35	27.20	26.98	25.09	24.77	22.99	23.66	24.86	22.15	19.21
2004	21.72	21.94	22.82	24.71	24.08	23.30	22.35	23.94	24.80	25.38	22.61	18.65
2005	18.29	24.22	26.57	26.99	25.97	25.25	24.68	24.13	24.66	24.22	22.49	19.65
2006	21.13	24.46	25.57	26.63	25.67	25.20	24.77	24.35	24.45	24.54	22.68	18.40
2007	19.73	21.80	23.63	26.92	25.70	25.63	24.61	24.20	24.28	24.60	21.13	19.87
2008	18.97	19.69	23.02	24.83	24.69	24.40	24.01	23.53	24.27	23.62	20.74	20.60
2009	22.62	23.05	23.02	28.61	27.30	25.79	24.69	24.45	24.94	25.56	24.30	20.69
2010	19.38	20.37	22.30	25.61	24.66	24.32	23.51	23.94	24.10	24.50	21.69	20.73
2011	18.14	22.29	21.68	21.92	23.07	23.41	22.29	22.38	23.00	23.06	20.71	18.44
2012	19.56	22.18	20.86	24.48	24.43	23.63	23.55	23.62	23.19	23.31	21.83	19.66
2013	20.84	21.24	22.13	25.62	26.02	24.11	24.31	23.90	24.22	24.57	23.80	23.51
2014	20.35	24.72	25.06	26.45	26.34	25.22	25.60	24.72	24.78	24.92	20.93	20.25
2015	19.25	25.59	27.90	29.74	28.45	25.85	25.80	24.51	24.30	25.84	21.27	23.82
2016	20.02	22.64	25.94	26.83	25.96	25.13	24.98	24.76	24.36	24.66	23.58	21.52
2017	21.08	20.59	25.61	27.91	25.79	25.03	24.53	24.03	24.46	25.34	22.83	18.86
2018	19.56	21.33	24.15	25.76	24.90	23.82	23.95	23.88	23.92	24.23	21.45	20.82

ESI: environmental stress index,
MetS: meteorological station, and
The values are compared with the ambient environmental condition of 30 ˚C.

Table 5 - Computed ESI for Markudi MetS (Benue State)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1987	20.51	22.10	25.92	26.98	26.07	25.46	25.56	24.96	25.12	24.68	23.06	19.50
1988	20.62	21.17	24.70	25.21	27.95	25.80	25.44	25.70	25.08	25.43	24.83	23.52
1989	21.43	22.80	24.19	26.55	26.02	26.05	25.12	24.89	25.08	25.02	24.98	21.78
1990	20.47	22.99	26.69	28.38	26.09	25.38	24.74	25.25	24.81	25.35	23.91	19.98
1991	20.31	22.16	27.57	27.05	26.56	25.28	24.60	23.67	24.85	25.34	24.98	21.09
1992	20.81	23.06	26.38	26.16	25.23	25.69	25.37	25.12	25.00	24.65	23.92	19.62
1993	20.07	22.25	25.97	27.04	26.10	24.86	24.01	24.86	24.99	25.43	21.59	19.22
1994	19.23	23.36	26.38	26.84	26.48	25.40	24.60	25.05	24.94	24.89	21.45	20.44
1995	21.83	22.34	27.50	25.58	25.75	25.19	24.91	24.89	24.15	25.13	24.08	20.81
1996	20.78	21.83	25.28	27.21	27.26	25.78	25.18	24.93	25.44	25.56	25.22	22.05
1997	22.04	24.36	24.59	26.36	25.66	25.74	25.05	25.08	24.20	24.73	24.83	20.66
1998	21.79	23.63	29.24	25.72	25.85	24.21	25.18	24.74	25.27	25.82	24.30	21.31
1999	20.91	21.84	25.65	26.98	26.65	25.65	25.59	24.75	25.07	25.40	24.80	20.89
2000	20.54	22.58	26.95	26.92	25.87	25.93	24.92	25.11	24.86	24.25	22.65	21.44
2001	21.87	23.37	27.61	28.05	26.89	24.89	24.98	25.17	25.22	25.48	24.66	23.45
2002	22.91	25.35	25.40	26.79	24.78	25.32	25.03	24.82	24.81	25.42	25.95	23.22
2003	20.63	24.20	26.40	28.39	26.52	25.80	25.57	25.15	25.22	25.41	21.96	22.78
2004	22.10	26.51	27.14	27.04	26.70	25.47	25.51	24.48	24.36	24.16	22.01	22.54
2005	24.07	24.88	25.37	24.48	24.90	24.84	24.69	25.24	25.62	24.60	23.51	20.40
2006	19.52	23.87	25.31	27.76	26.37	24.68	24.43	25.11	24.88	25.36	25.84	20.60
2007	19.47	27.00	28.35	28.94	26.05	25.06	23.87	23.56	22.66	22.50	23.48	20.63
2008	20.39	24.45	25.22	27.15	25.45	24.57	24.35	24.18	24.68	24.41	22.55	20.05
2009	19.73	23.31	23.22	24.62	24.67	24.34	23.80	23.53	23.41	23.84	22.48	19.40
2010	20.78	20.99	22.98	24.99	24.60	24.36	24.42	24.07	24.15	24.06	23.96	19.47
2011	19.25	22.23	25.03	24.21	23.68	24.26	23.33	23.62	23.65	23.50	22.71	20.43
2012	21.39	20.98	22.50	25.45	24.73	24.50	24.11	24.28	24.17	23.80	23.27	22.12
2013	19.87	21.99	24.35	24.13	23.68	23.50	24.41	23.99	24.39	24.47	24.20	22.95
2014	20.17	21.56	24.53	24.08	24.40	24.19	23.65	23.83	24.20	24.72	23.16	19.84
2015	19.50	23.36	24.71	25.69	26.27	25.29	23.87	24.68	24.64	25.60	22.93	20.80
2016	17.71	21.85	27.35	26.99	25.90	25.06	24.77	25.21	24.88	25.11	24.20	21.89
2017	21.54	22.81	26.86	26.89	26.19	25.69	25.53	24.99	25.02	25.99	25.56	21.86
2018	19.66	26.63	27.68	27.70	26.81	25.60	25.00	24.60	23.99	24.39	24.28	20.25

ESI: environmental stress index,
MetS: meteorological station, and
The values are compared with the ambient environmental condition of 30 ˚C.

Table 6 - Monthly comparative computed ESI across the five MetS and MANOVA

Reliability Statistics			Hotelling's T-Squared Test				
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items	Hotelling's T-Squared	F	df1	df2	T-value
0.821	0.901	12	1025.392	87.355	11	149	**0.000**

	Descriptive Statistics (N = 32, 1987-2018)					MANOVA	
	Benin	Ondo	Bida	Minna	Markudi	F	*P-value*
JAN	24.99±1.89	23.28±1.71	22.23±6.56	19.98±1.11	20.68±1.23	12.386	0.000
FEB	26.81±1.94	25.00±1.53	22.90±2.02	22.05±1.65	23.18±1.59	37.680	0.000
MAR	27.34±1.43	25.93±0.84	26.07±1.65	24.41±1.84	25.84±1.58	15.175	0.000
APR	27.13±1.44	25.83±0.77	26.79±1.30	26.36±1.39	26.45±1.31	4.780	0.001
MAY	26.74±1.05	25.44±0.62	26.13±1.20	25.80±1.03	25.82±0.99	7.592	0.000
JUN	26.01±0.77	24.79±0.53	25.60±0.78	24.81±0.68	25.12±0.63	19.264	0.000
JUL	25.33±0.62	24.23±0.48	25.21±0.86	24.42±0.77	24.74±0.62	15.682	0.000
AUG	24.98±0.51	23.72±0.46	24.93±0.70	24.07±0.52	24.67±0.58	31.126	0.000
SEPT	25.42±0.53	24.22±0.39	25.06±0.80	24.14±0.50	24.65±0.63	27.944	0.000
OCT	25.80±0.68	24.66±0.56	25.24±1.06	24.28±0.89	24.83±0.76	16.469	0.000
NOV	26.31±0.96	25.21±0.92	23.14±1.04	21.85±1.09	23.79±1.22	87.912	0.000
DEC	25.46±1.40	24.42±1.00	20.61±1.45	20.29±1.36	21.09±1.25	107.393	0.000

Results in Mean±S.D with levels of significant ($p < 0.05$) difference.
ESI: environmental stress index,
MetS: meteorological station, and
MANOVA: multivariate analysis of variance.

Table 7 - Pearson's correlations of ESI within 12-month (N=32, 1987-2018) across five MetS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Jan	1											
Feb	0.423**	1										
Mar	0.268**	**0.654****	1									
Apr	-0.050	0.376**	0.558**	1								
May	0.006	0.366**	0.543**	**0.814****	1							
Jun	0.166*	0.491**	0.549**	**0.707****	**0.764****	1						
Jul	0.106	0.343**	0.488**	**0.622****	**0.672****	**0.790****	1					
Aug	0.051	0.220**	0.363**	0.517**	0.564**	**0.709****	**0.776****	1				
Sept	0.193*	0.324**	0.382**	0.446**	0.491**	**0.646****	**0.671****	**0.795****	1			
Oct	0.131	0.386**	0.371**	0.492**	0.542**	**0.604****	0.590**	**0.669****	**0.789****	1		
Nov	0.361**	0.595**	0.391**	0.174*	0.251**	0.362**	0.257**	0.231**	0.409**	0.566**	1	
Dec	0.415**	0.585**	0.316**	0.073	0.179*	0.257**	0.196*	0.076	0.264**	0.379**	**0.793****	1

***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*

The monthly ESI showed that February (late dry season), August (dry-break), September (late wet season) and December (early dry season) had significant impacts of environmental stress over that past 32-year period. The Beta-value (under the Standardized Coefficients) indicated that April, July and August had higher environmental stress. For every unit increase in the computed ESI, corresponding 0.181, 0.099 and 0.682 of the environmental stress would be felt in April (early wet season), July (end of the early wet season) and August (dry-break), respectively. The order of environmental heat stress across the months iss: August (0.682) > April (0.181) > July (0.099).

The normal probability plot of the regression standardized residue showed that the data of the ESI were well distributed along the diagonal axis, to valid the model and establish homoscedasticity (Fig. 1). The computed ESI was meritorious (KMO = 0.859) and valuable ($\chi 2 = 1494.061$, $p < 0.05$) to be subjected to factor analysis (Kaise, 1974; Cerny and Kaiser, 1977) (Table 9).

The principal components analysis (PCA) showed that influences of environmental stress indications of the studied periods (n = 32 years) were alike for the rainy periods (April to October) as classified under Component 1. The early (November and December) and late (January to March) dry periods, except February also had the same indications as shown under the Component 2. Component 1 explained nearly 50 % variance while Component 2 explained nearly 18 % variance.

FUNDING

The work was supported by the World Bank through its Centre of Excellence in Agricultural Development and Sustainable Environment (CEADESE) for a PhD student: [PG 09/ 0181] in Federal University of Agriculture, Abeokuta, Ogun State, Nigeria (FUNAAB).

ACKNOWLEDGEMENTS

The utmost appreciation goes to the World Bank for its CEADESE, in FUNAAB. Olaide Khadijat, Qanita Roореromi and Yasir Ooreoluwa are appreciated for their support during this PhD project.

Table 8 - Multiple regression analysis of ESI across the 12 months (N=32, 1987-2018)

Model Summary[b]						MANOVA	
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson	F	P-value
1	0.801[a]	**0.642**	0.612	0.883157	0.678	21.940	**0.000[b]**

a. Predictors: (Constant), Dec, Apr, Jan, Sept, Mar, Jul, Feb, Oct, May, Nov, Aug, Jun
b. Dependent Variable: MetS ESI

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	t-value	Collinearity Statistics Tolerance	Collinearity Statistics VIF
ESI	(Constant)	15.418	2.546		6.055	**0.000**		
	JAN	-0.041	0.023	-0.106	-1.790	0.075	0.700	1.429
	FEB	-0.097	0.048	-0.166	-2.000	**0.047**	0.355	2.819
	MAR	-0.041	0.061	-0.051	-0.665	0.507	0.422	2.372
	APR	**0.181**	0.101	**0.169**	1.789	0.076	0.274	3.656
	MAY	-0.112	0.131	-0.085	-0.856	0.393	0.247	4.043
	JUN	-0.356	0.183	-0.207	-1.946	0.054	0.216	4.634
	JUL	**0.099**	0.172	**0.056**	0.574	0.567	0.259	3.863
	AUG	**0.682**	0.199	**0.358**	3.421	**0.001**	0.223	4.492
	SEPT	-0.522	0.192	-0.279	-2.718	**0.007**	0.231	4.331
	OCT	-0.051	0.144	-0.034	-0.351	0.726	0.259	3.854
	NOV	-0.005	0.073	-0.007	-0.071	0.944	0.262	3.812
	DEC	-0.263	0.051	-0.463	-5.176	**0.000**	0.305	3.283

a. Dependent Variable: MetS ESI

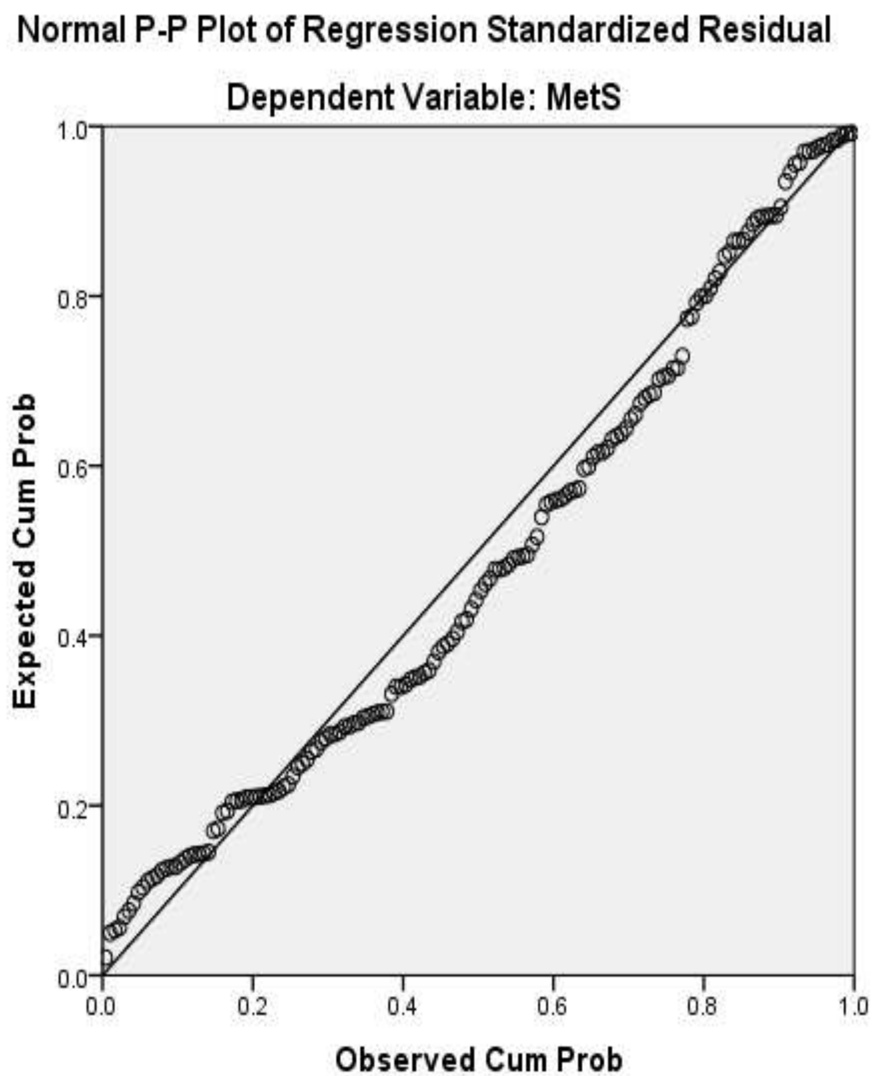

Figure 1 - Normal probability plot of the computed ESI across 12-month (N=32, 1987-2018)

Table 9 - Principal components analysis of the 12-month environmental stress index

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**0.859**
Bartlett's Test of Sphericity	Approx. Chi-Square	1494.061
	Df	66
	Sig.	**0.000**

Component Matrix[a]	Component 1	2	3
JAN	0.272	**0.613**	-0.020
FEB	0.641	**0.519**	0.336
MAR	0.695	0.152	**0.487**
APR	**0.734**	-0.364	0.391
MAY	**0.786**	-0.310	0.294
JUN	**0.878**	-0.195	0.093
JUL	**0.823**	-0.300	-0.061
AUG	**0.767**	-0.379	-0.340
SEPT	**0.794**	-0.128	-0.456
OCT	**0.800**	-0.011	-0.399
NOV	0.587	**0.644**	-0.190
DEC	0.466	**0.744**	-0.097
Total	5.992	2.154	1.130
% of Variance	49.932	17.954	9.420
Cumulative %	49.932	67.885	77.305

Indication of the local environmental stress throughout the rainy periods could mean the possibility of shortage or irregular rainfall distribution.

CONCLUSION

The verification of climate variability indication across four chosen (Benue, Edo, Niger and Ondo) States in Nigeria was done by adopting the established environmental stress index (ESI) using three (ambient temperature, relative humidity and solar radiation) climate data of 32 years. The values of ESI were higher than 30 °C in Edo State (Benin meteorological station; February to April 2005, and February to May 2007) and Niger State (Bida meteorological station; April 2006, and January 2013 and 2014).

Reliability of the 32-year data had good internal consistency with a Cronbach's value of 0.821. The Hotelling's *t*-squared statistic (t^2) indicated that the data distribution was highly significant (F = 87.355, p = 0.000). A very strong correlation (0.814) existed between April and May at 0.01 statistical level of the Pearson's Momentum analysis. A 64.2 % variance in data was explained by the multiple regression model, with Durbin-Watson value of less than 2 to indicate positive autocorrelation. The ESI data were well distributed along the diagonal axis of the normal probability plot of the regression thereby validating and establishing homoscedasticity for the model. The computed ESI was meritorious (KMO = 0.859) and valuable ($\chi 2 = 1494.061$, $p < 0.05$) for the factor analysis. The Principal Component Analysis produced two components; the component 1 had all the seven-month rainy season with higher eigenvalues than the five-month dry season in the component 2. The rainy seasons across the four study States could subject the farmers to environmental stress thereby being less productive and its seven month periods to shortage rainfall distribution. So, there is need for farmers' adaptation.

REFERENCES

Appiah K.S. (2014). [Space-time statistical analysis of malaria morbidity incidence cases in Ghana: A geostatistical modelling approach] Monograph of PhD, Edith Cowan University, Perth. *In:* Frimpong, K. (2015). [An appraisal of experiences of climate change and adaptive response to heat stress by farmers in Rural Ghana]: thesis of PhD, Edith Cowan University, Ghana, 216p. Accessed on 15 October 2017 from http://ro.ecu.edu.au/theses/1653.

Barrett B., Charles J.W. and Temte J.L. (2015). Climate change, human health, and epidemiological transition (Review). *Preventive Medicine,* 70: 69-75.

Collins J.M. (2011). Temperature variability over Africa. Bulletin of the American meteorological society. *In:* Frimpong, K. [An appraisal of experiences of climate change and adaptive response to heat stress by farmers in Rural Ghana]: thesis of PhD, Edith Cowan University, Ghana, 2015. -- 216p. Accessed on 15 October 2017 from http://ro.ecu.edu.au/theses/1653.

Ebi K.L., Smith J.B and Burton I. (2006). [Integration of public health with adaptation to climate change: lessons learned and new directions]: CRC Press.

Epstein Y. and Moran, D.S. (2006). Thermal comfort and the heat stress indices. *Industrial Health,* 44: 388–398.

Ethan D.C., Radley, M.H. and Alex, S. (2018). Temperature and humidity based projections of a rapid rise in global heat stress exposure during the 21st Century. *Environmental Research Letter,* 13 (014001): 1-9. https://doi.org/10.1088/1748-9326/aaa00e.

Fosu-Mensah B.Y., Vlek P.L. and MacCarthy, D.S. (2012). Farmers' perception and adaptation to climate change: a case study of Sekyedumase district in Ghana. *Environment, Development and Sustainability,* 14(4): 495-505.

Frimpong K. (2015). [An appraisal of experiences of climate change and adaptive response to heat stress by farmers in Rural Ghana]: thesis of PhD, Edith Cowan University, Ghana, 216p. Accessed on 15 October 2017 from http://ro.ecu.edu.au/theses/1653.

Frimpong K., Oosthuizen J. and Van Etten E. (2011). The extent of heat on health and sustainable farming in Ghana–Bawku East. *Sustainable Agriculture Research,* 3(3): 56p.

Haines A., Kovats R.S., Campbell-Lendrum D. and Corvalan C. (2006). Climate change and human health: impacts, vulnerability and public health. *Public Health*, 120(7): 585-596.

Im E.S., Pal J.S. and Eltahir E.A.B. (2017). Deadly heatwaves projected in the densely populated agricultural regions of South Asia. *Sci. Adv.,* 3: e1603322.

Kenney W.L., DeGroot D.W. and Alexander Holowatz L. (2004). Extremes of human heat tolerance: life at the precipice of thermoregulatory failure. *Journal of Thermal Biology*, 29: 479-485.

Kjellstrom T. (2009). Climate change, direct heat exposure, health and well-being in low and middle-income countries. Global Health Action, 2p. *In:* Frimpong, K. (2015). [An appraisal of experiences of climate change and adaptive response to heat stress by farmers in Rural Ghana]: thesis of PhD, Edith Cowan University, Ghana, 216p. Accessed on 15 October 2017 from http://ro.ecu.edu.au/theses/1653.

Kjellstrom T. (2012). [The hothaps program for climate change impact assessment and prevention]: Umea University and Australian National University. *In:* Frimpong, K. (2015). [An appraisal of experiences of climate change and adaptive response to heat stress by farmers in Rural Ghana]: thesis of PhD, Edith Cowan University, Ghana, 216p. Accessed on 15 October 2017 from http://ro.ecu.edu.au/theses/1653.

Kjellstrom T. and McMichael A.J. (2013). Climate change threats to population health and well-being: the imperative of protective solutions that will last. Global Health Action, 6: 20816. *In:* Buapun, P., Yanyong, I., Weerayuth, P., Monchai, P. and Kritsada, P. (2016). [Climate change and urban health vulnerability]: working paper series, Asian cities climate resilience, 31: 35.

Lundgren K., Kuklane K., Gao, C. and Holmer I. (2013). Effects of heat stress on working populations when facing climate change. *Industrial Health,* 51(1): 3-15.

Maté J. and Oosthuizen J. (2011). Global warming and heat stress among western Australian mine, oil and gas workers.

Moran D.S., Pandolf K.B., Shapiro Y., Heled Y., Shani Y., Mathew, W.T. and Gonzalez R.R. (2001). An environmental stress index (ESI) as a substitute for the wet bulb globe temperature (WBGT). *Journal of Thermal Biology,* 26: 427-431.

New M., Hewitson B., Stephenson D.B., Tsiga A., Kruger A., Manhique A., Gomez B., Coelho A.A.S., Masisi D.N., Kululanga E., Mbambalala E., Adesina F., Saleh H., Kanyanga J., Adosi J., Bulane L., Fortunata L., Mdoka M.L. and Lajoie R. (2006). Evidence of trends in daily climate extremes over southern and West Africa. *J. Geophys. Res.,* 111: D14102.

Pal J.S. and Eltahir E.A.B. (2015). Future temperature in southwest Asia projected to exceed a threshold for human adaptability. *Nat. Clim. Change,* 6: 197-200.

Pascual M., Ahumada J.A., Chaves L.F. and Bouma M. (2006). Malaria resurgence in the east African highlands: temperature trends revisited. *Proceedings of the National Academy of Sciences,* 103(15): 5829-5834. http://dx.doi.org/10.1073/pnas.0508929103.

Thornton P.K., Ericksen P.J., Herrero M. and Challinor A.J. (2014). Climate variability and vulnerability to climate change: a review. *Global Change Biology,* 20: 3313-3328.

UNDP (United Nations Development Programme) (2020). [COVID-19 and human development: assessing the crisis, envisioning the recovery (UNDP, 2020)]. Accessed on June 16, 2021 http://hdr.undp.org/en/hdp-covid.

USACHPPM (US Army Center for Health Promotion and Preventive Medicine) (2003). [Heat stress control and heat casualty management (TB MED507/AFPAM 48-152)]: Aberdeen Proving Ground, Mid, US.

WHO (World Health Organization) (2012). [Regional strategy for protecting health from climate change]: The World Health Organization Regional Office for Southeast Asia, Delhi. *In:* Buapun P., Yanyong I., Weerayuth P. and others (2016). [Climate change and urban health vulnerability]: working paper series, Asian cities climate resilience, 31: 35.