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Climate Variability and Heat Stress Index have Increasing Potential Ill-health and Environmental Impacts in the East London, South Africa

Orimoloye Israel Ropo*, Mazinyo Sonwabo Perez, Nel Werner and Iortyom Enoch T.

Department of Geography and Environmental Science, University of Fort Hare,
Private Bag X1314, Alice, 5700, Eastern Cape Province, South Africa.

**Corresponding author's email ID: orimoloyeisrael@gmail.com*

**Orcid ID: 0000-0001-5058-2799*

Abstract

Impacts identified with climate variability and heat stress are already obvious in various degrees and expected to be disruptive in the near future across the globe. Heat Index describes the joint impact of temperature and humidity on the human body. Therefore, we investigated the trend of relative humidity, temperature, heat index, and humidex and their likelihood impacts on human health in the East London over 3 decades. Real-time data for daily average maximum temperature and relative humidity between 8:00 GMT and 18:00GMT hour for the period of 1986-2016 were retrieved from the South Africa Weather Service and analyzed using the new empirical heat index method to assess heat stress index in the study area. Results demonstrated that summer and autumn season (December to May) of various years over East London from 1986 to 2016 exceed high heat index values that is, when heat index is 38°C above. It is evident that summer and autumn months are more vulnerable to heat extreme and humidex as both shows high limits. The humidex and heat index increased annually with 0.03% and 0.9% respectively throughout the study period. The increment in the various indices showed highly significant ill health and environmental health impact on humans especially during prolonged exposure.

Keywords: climate variability; human health; environmental health; implications; heat index

INTRODUCTION

Globally, increased temperatures have induced more pressing, continuous, and vast extreme heat occurrences, which are now viewed as a significant issue for public and environmental health [1]. Increments are expected in both "exceedingly irregular" occasions, for example, those in Central Asia and Russia in 2010, the United States in 2012, and Australia in 2015, and "exceptional" circumstances, which do not happen under present-day climate situations [2]. A recent study opines that the likelihood of extreme heat events in some parts of the world such as Eastern China, Europe have increased sixtyfold since the 1950s which might be a result of anthropogenic activities and recent development in the region [3]. Furthermore, an investigation of extreme heat since 2003 in Europe demonstrates that a considerable lot of the extremes recorded during this occasion are at least double as likely in the 1950s [4, 5]. In North America, there is the expected increment in the number of hot days over the region [6]. Moreover, some African nations including South Africa likewise experience the ill effects of the outcomes of climate inconstancy in relation to heat-related threats [7, 8].

It is well known that the discomfort that occurs in warm weather depends on the significant degree of temperature and humidity present in the air. The linkage between mortality and temperature have been examined by some researchers [9-11] but more still need to be done, because most of the studies used a threshold that is suitable to their location in order to assess heat index in different location with their own peculiarity including weather pattern and geographical location. The climate in the recent years is characterized by rapidly increased intensity of extreme heat, and this has numerous effects on human well-being and health. Health implications of climate variability have become a focal point and considered as a crucial issue among the researchers [12].

Several indices have been employed in studying the human health implications of climate variability and extreme weather. Some of the studies used heat index (United States Weather Service [13, 14]), humidex (Canadian meteorologist; [15]), wet-bulb globe temperature [16, 17] and apparent temperature [18, 19] to assess heat index indications of climate variability on human health, while other researchers have to use different algorithm to assess heat index, although with varying shortcomings. In assessing the extreme heat implications on human thermal comfort and health, most of study, have used ambient temperature (maximum, minimum and average temperature) [20-22]. Moreover, extreme weather implications cannot be fully assessed with the temperature only, but other indicators such as solar radiation, wind, and relative humidity should be considered to give a precise effect on human health. Among these indicators, the immediate surroundings have more effects on wind and radiation, for example, wind speed is reduced by the buildings effects as well as trees.

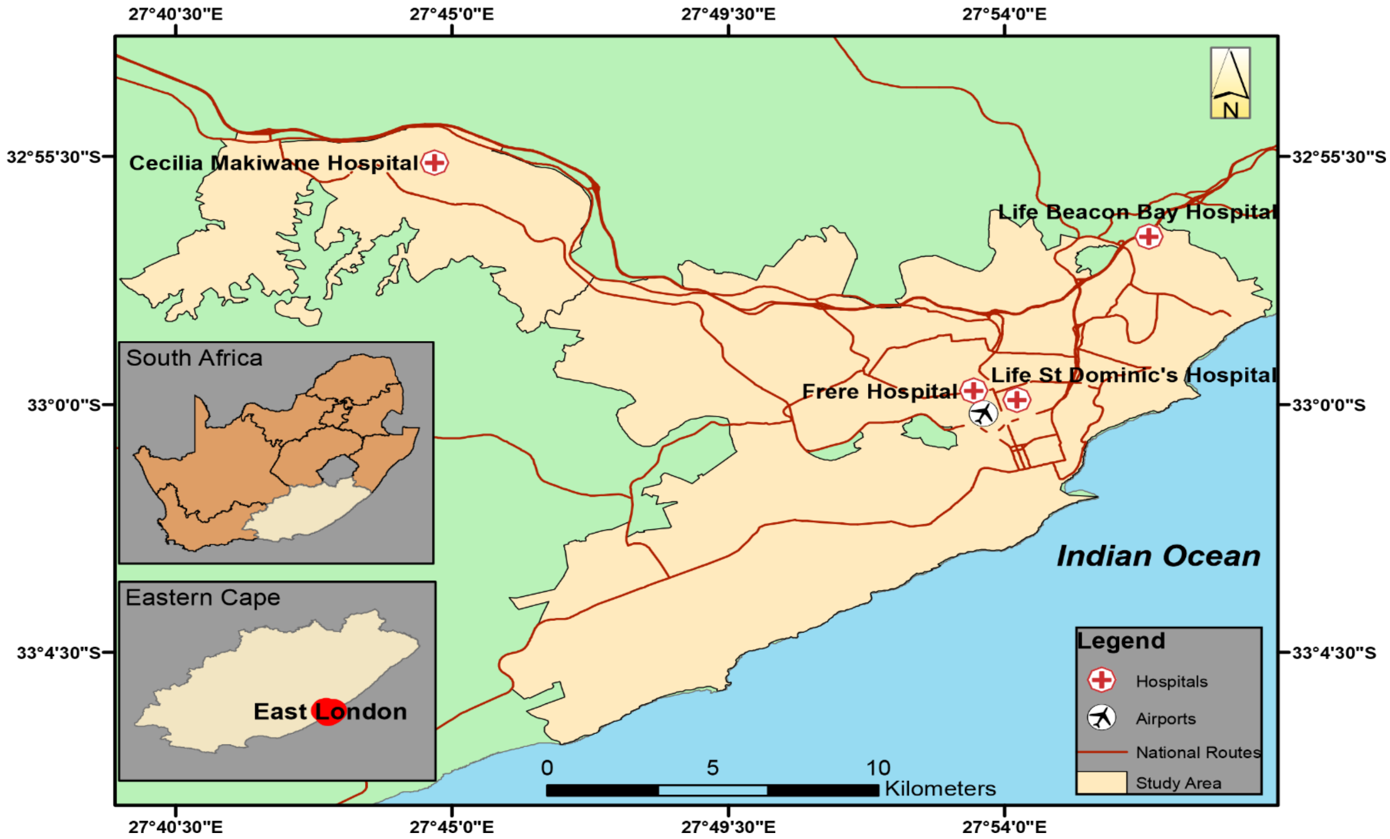

Figure 1: East London Area in Buffalo City metropolitan municipality, South Africa.

Solar radiation is effected by localized events, which include cloudiness and visibility. If wind and radiation are to be considered as heat index variables, they are most suitable for a location as they can vary significantly in values over a short distance [23]. The other two factors that are popularly used include relative humidity and air temperature because they are not spatially varied and these can be utilized to give a signal of the thermal comfort status over a large area [23]. Therefore, this study appraised the indications of climate variability and heat stress index on human health using new empirical methods of heat index and humidex for the period of 1986 to 2016 spanning 30 years over East London, South Africa (Fig 1).

MATERIALS AND METHODS

East London City (EL), the hub of Buffalo City Metropolitan Municipality (BCMM), represents one of the largest South African urbanized areas with Latitude 32° 59′ 0″S and Longitude 27° 52′ 0″E. EL's location is in the South-eastern area of the country close to the Indian Ocean and which is well exposed to the movement of southeasterly wind over a short distance from the ocean to the land and this defines the temperate weather context characterized by mild and raining winters and dry and hot summers.

The real-time data of monthly daily average maximum temperature and relative humidity between 8:00 GMT and 18:00GMT hour for the period of 1986-2016 was obtained from the South African Weather Service to assess the heat stress index in the study area.

Heat Index

The calculation of heat index, described as an individually perceived air temperature, incorporated with relative humidity was conducted using South African Weather Service's meteorological parameters (air temperature and humidity). The heat index measures the evaporative heat between the human body and the surrounding air (environment). Using the heat index is the more appropriate measure to assess the significant effects of heat on human body than using temperature only. Using an algorithm, Steadman [24] propose the method for the actual estimation of the human-discerned equivalent temperature, Steadman [24] proposed algorithm comprised a group of climatic variables such as vapor pressure or dimension of human skin surface and clothing cover or resistance to heat movement or activities. The algorithm approximates the heat index in degrees Fahrenheit, to a confidence of ±1.3 °F. It is the outcome of a multivariate fit (temperature equivalent to or greater than 27°C (80°F) and relative humidity equivalent to or greater than 40%) to what human body can manage [24, 25]. This condition is constituent with the NOAA National Weather Service (NWS) threshold (with the exception of the qualities at 32 °C (90°F) and 45%/70% relative humidity which fluctuate unrounded by less than - 1/+1, respectively). The Heat Index is calculated as follow:

$$HI = (-42.379 + 2.04901523*T) + (10.14333127*R - 0.22475541*T*R) - (0.00683783*T^2 - 0.05481717*R^2) + (0.00122874*T^2*R + 0.00085282*T*R^2 - 0.00000199*T^2R^2) \quad \text{(eq. 1)}$$

Where

All the figures in the equation are constant;

HI = Heat index (usually expressed as an apparent temperature in Fahrenheit)

T = Temperature in Fahrenheit

R = Relative humidity (%)

the substitute set of constants for this condition is within 3 degrees of the NWS master index for all humidity from 0% and all temperatures in the vicinity of 22°C (70°F) and 46 °C (117°F) and all heat index < 65°C (150 °F) is the New Empirical Model (NEM) [26] below;

$$HI= K_1 + K_2T + K_3R + K_4TR + K_5T^2 + K_6R^2 + K_7T^2R + K_8TR^2 + K_9T^2R^2 + K_{10}T^3 + K_{11}R^3 + K_{12}T^3R + K_{13}TR^3 + K_{14}T^3R^2 + K_{15}T^2R^3 + K_{16}T^3R^3 \quad \text{(eq. 2)}$$

Where Ks the constant *K's* and the standard value for irrespective environmental condition using NWS heat index and Ks are as follow*;*

$K_1 = 16.923$, $K_2 = 0.185212$, $K_3 = 5.37941$, $K_4 = -0.100254$, $K_5 = 9.41695 * 10^{-3}$, $K_6 = 7.28898 * 10^{-3}$, $K_7 = 3.45372 * 10^{-4}$, $K_8 = -8.14971 * 10^{-4}$, $K_9 = 1.02102 * 10^{-5}$, $K_{10} = -3.8646 * 10^{-5}$, $K_{11} = 2.91583 * 10^{-5}$, $K_{12} = 1.42721 * 10^{-6}$, $K_{13} = 1.97483 * 10^{-7}$, $K_{14} = -2.18429 * 10^{-8}$, $K_{15} = 8.43296 *10^{-10}$, $K_{16} = -4.81975 * 10^{-11}$.

Take for example using the equation above with the value of temperature 88 °F (32°C) and relative humidity value of 85%, the value of heat index would be 107 °F (42°C).

The estimation of the heat index permits the classification of temperature (ºC) as per four distinctive risk threshold levels with additional one from the present study, to which likely physical adverse signature compare (National Weather Service Weather Forecast Office Summer Weather Safety and other Heat Index: (1) less evident (21°C < HI < 25°) – fatigue with prolonged exposure; (2) Caution (26°C < HI < 32°C) - possible fatigue due to prolonged exposure and/or physical activity; (3) extreme caution (33°C < HI < 37°C) - sunstroke, muscle cramps, and/or heat exhaustion due to possible prolonged exposure and/or physical activity; (4) danger (38°C < HI < 48°C) - sunstroke, muscle cramps, and/or heat exhaustion, heart failure, cardiovascular heatstroke due to prolonged exposure and/or physical activity; (5) extreme danger (HI ≥ 49°C) - heat stroke, sunstroke, heart failure, skin disease.

Humidex

This index was developed by Canadian meteorologists and was first used to describe the impacts of humidity on human comfort. In a warm day, it will feel warmer if the relative humidity is high because human perspiration does not evaporate as easily especially when the humidity is high. A humidex value that is over 40°C is considered an extreme weather event [27]. When the humidex value reaches the 30°C, outdoor activity should be properly managed with special attention paid to the aged and the minors as well as the health of any adult individual [28].

Humidex value is an equivalent temperature (the temperature that human body would feel) given the temperature and relative humidity. The humidex equation is based on Masterson and Richardson [29], which was later adopted by Canadian meteorologist, but its variations are used around the world and the dew point temperature will be measured in Kelvin for the formula to work perfectly.

Humidex = T + *b*

$$b = (0.5555) * (a -10.0)$$

$$a = 6.11 * exp^{\left(5417.7530 * \left(\frac{1}{273.16} - \frac{1}{dew\ point+273.16}\right)\right)} \quad \text{(eq. 3)}$$

Where

T = Air temperature (in degree Celsius)

a and *b* = constants

Dew point= Dew point temperature (Fahrenheit)

If the air temperature and relative humidity are known, the equation will be used and is express as:

$$Td= T - \left(\frac{100-RH}{5}\right) \quad \text{(eq. 4)}$$

Heat index and humidex were modeled using Microsoft Excel to calculate the heat stress index for the study periods. This study will use the World Health Organization (WHO) standard thresholds for extreme heat exposure in the study area. Antecedently, the NWS method was rated too complicated for general use in environmental health study [30]. Nevertheless, due to the open-source of some statistical packages such as Gretl and Microsoft Excel are frequently recommended in climate and environmental health investigation, complex methods can now be more effectively actualized. The script's code from the heat index algorithm by NWS, 2011 was converted in a simple way that some statistical Software can utilize for example R, Microsoft Excel, and Gretl packages that can be applied to larger weather data sets.

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RESULT

Table 1: Observed Changes in Temperature and Humidity (1986-2016)

Average Monthly Hourly Maximum Temperature (^{o} C) 8:00-18:00				
Years	**Summer**	**Autumn**	**Winter**	**Spring**
1986-2000	27	25	22	23
2001-2016	29	27	23	26
Variation	2	2	1	3
Average Monthly Hourly Relative Humidity (%) 8:00-18:00				
1986-2000	84	77	76	82
2001-2016	83	77	76	83
Variation	-1	0	0	1

Table 1 summarizes changes in observed temperature and relative humidity over East London. Temperature shows increasing trend pattern across the season over the years of study. The variation between temperature in first 15 years (1986-2000) and later (2001-2016) are evident, temperature increased by 2^0C in summer and autumn, while the spring varies by 3^0C and 1^0C in winter. Relative humidity decreases in summer by -1% between the two periods (1986-2000, 2001-2016) while in autumn and winter remain unchanged (0%) and the spring season experienced an increment of 1% during the study period.

Table 2: Observed Heat Index and Humidex (1986-2016)

Mean Heat Index (^{0}C) 8:00-18:00				
Years	**Summer**	**Autumn**	**Winter**	**Spring**
1986-2000	30	26	23	24
2001-2016	36	32	24	27
Variation	6	6	1	3
Mean Humidex (^{0}C) 8:00-18:00				
1986-2000	35	32	26	28
2001-2016	36	32	26	29
Variation	1	0	0	1

Table 2 presents the observed heat index and humidex over the study area. The trend pattern of heat index in all seasons increased significantly and more evidently in summer and autumn with the value of 6 ^{0}C between the two periods (1986-2000 and 2001-2016) while spring increases by 3 ^{0}C and winter have the least by 1 ^{0}C. The changes in the heat index that occurred across the seasons indicate that there were fluctuations in climate pattern between the two periods and the increase of heat index in recent years is quite considerable. Average Humidex is presented in the later part of Table 2 revealed that the changes in humidex across the seasons are not much. For example, in autumn and winter where there were no changes in the humidex between the periods while summer and spring have humidex value of 1 ^{0}C.

Table 3: The risk to the human health from continued exposure to excessive heat (Adapted from the source: United States National Weather Service; [25])

Index Threshold	Severity Classification	Possible Adverse Effect
21-25	Less evident	Fatigue with prolonged exposure
26-32	Caution	Fatigue possible
33-37	Extreme Caution	Muscle cramps, sun stroke, heat exhaustion possible
38-48	Danger	Sun stroke, heart failure, sun burn, skin rashes, fainting possible
>49	Extreme Danger	Heat stroke, heart failure, skin rashes possible

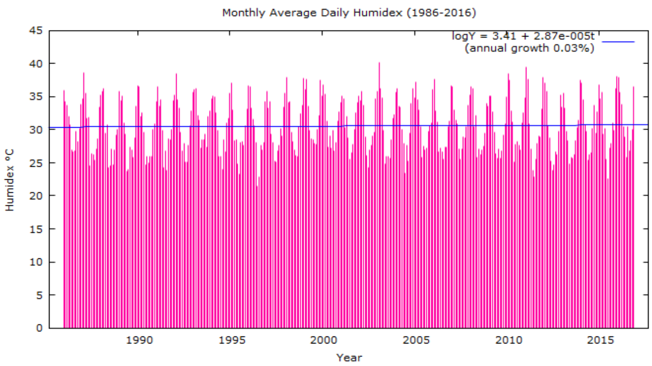


Figure 2: Monthly Average Daily Humidex (1986-2016).

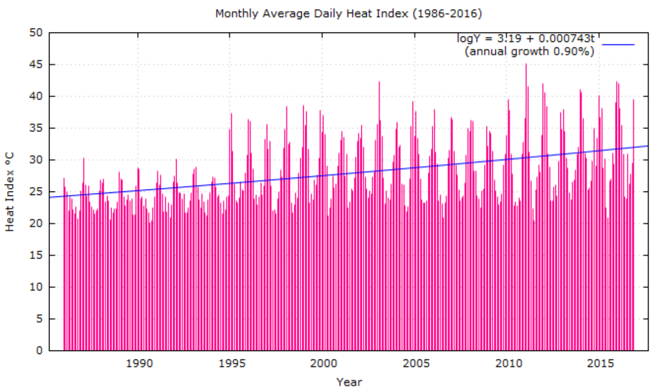
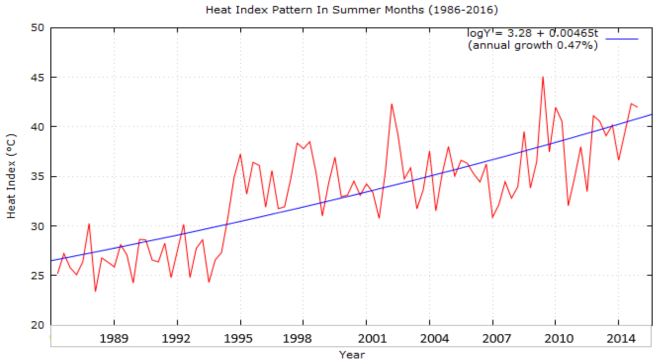


Figure 3: Monthly Average Daily Heat Index (1986-2016).

Seasonal trend of heat index (1986-2016)

Figure 4 a-d below presents the seasonal distribution of year-to-year annual heat index trend for the period of 1986 - 2016. Obviously, the high rate of inter-seasonal heat index trend appears in summer months with a growth percentage of approximately 0.45% annually followed by autumn months with the percentage of about 0.35% annually while winter and spring months increased annually with about 0.08% and 0.32% respectively throughout the study years. The seasonally increased heat index in the study area suggests that annually this phenomenon might have contributed immensely to the human health risk in the area and that this seasonal variation may play a vital role in raising public awareness regarding extreme heat events in the future.



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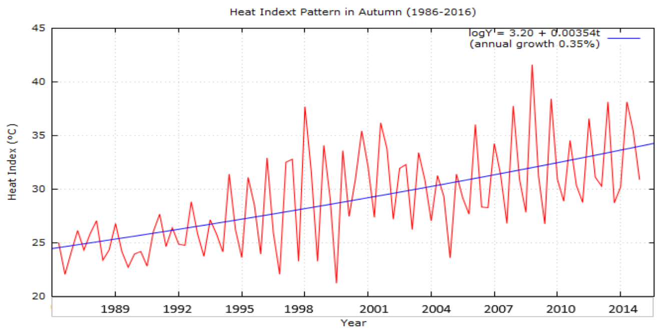

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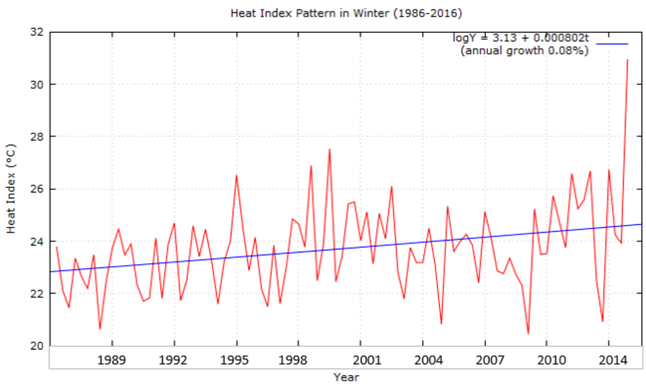

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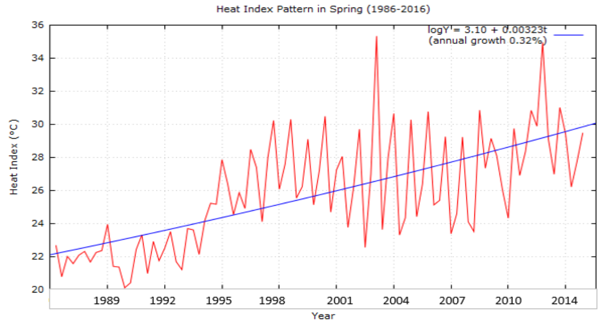
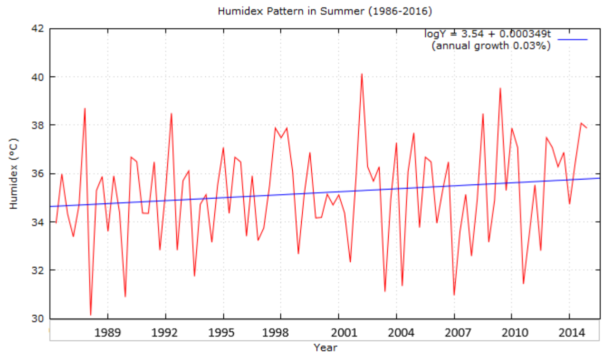


(d)

Figure 4: Seasonal Heat index pattern between 1986 and 2016; (a) summer months (b) autumn months, (c) winter months, and (d) spring months.

Seasonal trend of humidex (1986-2016)

The seasonal humidex distribution between 1986 and 2016 over EL is presented in Figure 5 a-d. Little changes in the overall annual distribution of humidex values in the study area were observed. The results show that the annual growth percentage of humidex is 0.03% (Figure 2). The analysis also revealed that summer months changed slightly with a percentage of about 0.03% annually while autumn shows a decrement in the annual growth rate of humidex throughout the years of study with the percentage of about –0.01% annually. Winter and spring months between 1986 and 2016 experienced a creeping variation with the percentage of about 0.01 and 0.04% respectively.



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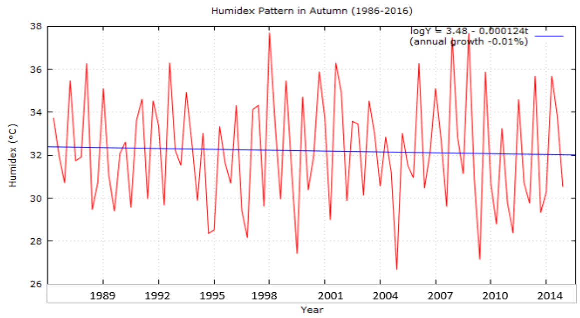

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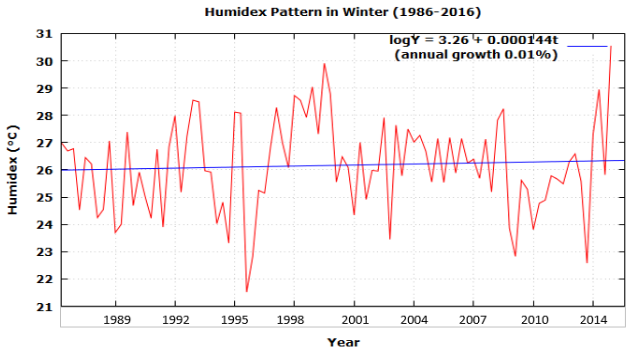

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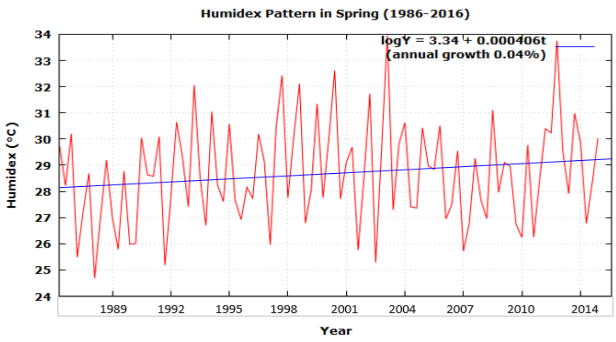

(d)

Figure 5: Seasonal Humidex pattern between 1986 and 2016; (a) summer months (b) autumn months, (c) winter months, and (d) spring months.

DISCUSSION

Increase in Indices and their seasonal shift

The investigation of heat stress index demonstrates that most of the autumn and summer seasons influenced by the heat index and that the mean heat index value in summer ranges from 30^{0}C-36^{0}C during the 30 years. During these summer months, the likelihood for serious human discomfort and heat-related illnesses is eminent. This coastal city experiences the most pronounced estimation of the heat index in February 2011 with the value of 45^{0}C, and in January (2012, 2016) and February (2003, 2016) when it reaches 42^{0}C (Figure 3). Such value could lead to heat cramp, heat stroke, heart failure, and heat exhaustion (diarrhea) that may result in morbidity and a possible rise in the death rate [19, 31]. The heat index has increased in recent years in the study area. The pattern drawn with the assistance of average seasonal heat index variation from 1986-2016 demonstrated a significant rise in the heat index in both the summer and autumn months (Table 2, Figure 4 and 5). The aggregate increase calculated is 6ºC in summer and autumn months, while 1 ºC and 3ºC in winter and spring months respectively which is statistically significant in climate study (Table 2). Figure 2 and 3 present the changes in heat index and humidex respectively throughout study period. Obviously, the heat index increase was evident in summer and the increase turns out to be less gradual as the season shifts to the winter months (Figure 3). Overall, the results revealed, that the humidex threshold (Figure 2) increased slightly with 0.03% annually, which implies how weak the function of the index is in the study area. Since the temperature and relative humidity in the area increased during the study period, humidex should reflect this increment in the threshold as this might be because of the unsuitability of the index in the region [32]. Secondly, Figure 3 reveals that the heat index increased with the percentage of about 0.9% annually throughout the study period and this increment is high since it presents significant and substantial implications on human health with prolonged exposure [14]. The changes in indices are attributable to the fluctuation in climate variability in the study area.

Corresponding changes in indices distributions

Climate and weather extremes, for example, heat wave, cold front, flood, and drought can exert damaging impacts on human society. The EL area experienced increasing weather extreme (heat index) events, which are driven mostly by climate fluctuations that may be as a result of natural and anthropogenic factors which might have a great influence on local and regional climate [33, 34]. Therefore, the increased distribution of seasonal trend pattern of the heat index events might be a crucial element influencing adverse health risk for the EL residents [8]. In spite of well-known significant of heat index, studies have been made limitedly to make a dynamic seasonal distribution of it extremes because of climate fluctuation. This study presents recent growing rate for the seasonal trend pattern of the heat index.

Combination of Humidity and Heat can be deadly

Excessive heat occurrences are crucial from a humanitarian perspective, since they are a prime driver of mortality. In addition, prolonged exposure to such extreme event may result in environmental challenges such as drought, water dearth, and climate-related human migration and illnesses [35]. Evaporation is nature's method for cooling. Hot and humid climate are not only uncomfortable, but also harmful to those working or exercising during the incidence. Furthermore, hot and humid climate is dangerous and uncomfortable than hot and dry climate since high humidity moderates the evaporation of body sweat. Equation 1 and 2 show how heat index can be derived from relative humidity and temperature since the heat index measures how hot it truly feels to the body at a particular time when relative humidity is considered with the real temperature. For example, if the relative humidity is 60% and the temperature is 33 degree Celsius, the heat index value will be 41 degree Celsius and this value falls into the danger zone in the heat index threshold (Table 3) where it is advised that outdoor activities be postponed [36].

In recent years, researchers have discovered that a day's most astounding temperature is not enough or the best measure of the risk of extreme heat exposure. The presence of unwavering heat and humidity in the air can make an individual uncomfortable or unable to rest during hot days and most times, it is responsible for the deaths of many minors, elderly, and ill people [19, 31, and 37]. The elderly and sick are not the main individuals that heat kills. It likewise kills healthy youngsters, normally because they do not recognize the health risks of working in hot weather, particularly hot, moist weather. Whenever heat and humidity join to slow or moderate evaporation of perspiration from the human body, outdoor practice ends up evidently risky even for those that are healthy. Some of the key measures for adapting to heat are to drink plenty water to avoid drying out and to cool down and chill when feeling weariness, headache, high heartbeat rate or shallow breathing. Overheating can cause substantial, even life-threatening situations, for example, heat stroke, heart failure, diarrhea, fainting, exhaustion, and skin disease [38-40].

CONCLUSION

Heat index has turned into a matter of consternation in the context of EL alongside most other coastal city areas in the region as they have comparative climate features. The heat index analysis from 1986-2016 in the study area depicts the consequential increase of both humidity and temperature in recent decades. It is evident that the temperature rises are responsible for the significant increase of these climatic features during summer months. Other than adverse effects of climatic condition, human health challenges, environmental degradation, the abatement and variation in climate results in a detectable rising trend of heat index in summer and autumn months. Assessing the discomfort and health challenges justify that, it must be emphasized that both heat and the moisture content of the environment play a crucial role in increased heat index factor of EL. Mean heat index values range from 24-36 ^{0}C in different season during the study period. Mean humidex value of 1986-2016 has shown a creeping rise in the temperature humidity index (humidex) throughout the study period.

This study recommends that the public health expert should provide accurate written and verbal instructions, frequent training programs and other information on heat stress index, as these will play a crucial role in combating the impacts of climate variability and heat stress index. Self-limitation of heat exposure must be promoted and health professional's early detection of symptoms of extreme weather event should be encouraged.

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