Scientific Online

OPEN JOURNAL OF ATMOSPHERIC AND CLIMATE CHANGE
Volume 1, Number 1, MAY 2014

OPEN JOURNAL OF ATMOSPHERIC AND CLIMATE CHANGE

A Review and Assessment of Applicability of the Heat Stress Indices in Kenyan Weather Forecast

Victor Ongoma[1]*, John Nzioka Muthama[2]

[1] *Department of Meteorology, South Eastern Kenya University, P.O. Box 170-90200, Kitui (K)*
[2] *Department of Meteorology, University of Nairobi (K)*
***Corresponding author**: victor.ongoma@gmail.com

Abstract:
The weather and climate of any given place is an environmental resource, it greatly determines the socio-economic and political life of humans and other living things.
The packaging of weather information especially the forecast into a way that can easily be interpreted and understood by end users is of very important. Temperature is one of the weather parameters that have significant impact of human comfort and the wellbeing of other living things. Thermal stress is an important factor in many industrial situations, games and military operations among others. It therefore calls for accurate and timely forecast of the same and dissemination to the public for human safety and comfort.
There exist three types of heat strain indices: rational, empirical and direct indices. The study tested the applicability of Discomfort Index (DI) in Kenyan daily weather forecast using both observed and forecast data from Consortium for Small-Scale Modelling (COSMO) model used by Kenya Meteorological Department (KMD).
The discomfort index (DI) forecasted by the Small-Scale Modelling (COSMO) model gives a relatively good representation of the observed and the study thus recommends that KMD adopt it in its forecast.

Keywords:
Human Comfort; Discomfort Index; COSMO

1. Introduction

Temperature is one of the most important parameters that influence human comfort. Temperature affects the thermal comfort and physiological ability of living things and thus sensitive for human comfort and survival. It is essential since it determines the output of workers in several industries, sportsmen/women at training and competitions and military officers in their operations among others.

Weather stress index is normally designed to assess the frequency and magnitude of the most uncomfortable weather conditions. Generally, translation of the stress in terms of physiological and psychological strain is complex. There are many indices that have been suggested, categorized into three groups: indices that are based on calculations involving the heat balance equation (rational indices), indices that are based on objective and subjective strain (empirical indices), and measurements of environmental variables (direct indices). Owing to their complexity, the first two groups are not applied in day to day life use. Direct indices; Discomfort Index (DI) and Wet Bulb Globe Temperature (WBGT) are very easy to use [1].

The main objective of this paper is to review Heat Stress Indices (HIS) and give a more practical and effective HIS that can be adopted by KMD to add value to its daily weather forecast. The study specifically gives a comprehensive review of development of human comfort index and a test of the applicability of a number of comfort indices in Kenya.

The temperature forecast issued in Kenya by the KMD only highlights how low or high the temperature will reach without giving scientific interpretation of how the temperature range will affect man and other living things in the various localities. KMD uses Small-Scale Modelling (COSMO) model; a non-hydrostatic limited-area atmospheric prediction model.

A number of studies have been done especially in Europe; worst hit by extreme temperature to develop practical models used to predict human comfort based on temperatures.

Most discomfort indices evaluate the impact of heat stress on the individual; they usually take temperature, humidity or both into consideration while doing this Court [2] . In as early as 1905, Haldane[3] developed an index for heat load and claimed that changes in the wet bulb thermometer alone were enough to reflect the heat load. However, with time, environmental indices have been suggested that include wind speed. In 1957, Yaglou and Minard came up with Wet Bulb Globe Temperature (WBGT) [4] , which gained popularity owing to its simplicity and convenience of use. It is the most common heat stress index for describing environmental heat stress (Eq. 1).

$$WBGT = 0.7T_w + 0.2T_g + 0.1T_a \tag{1}$$

where T_g is black globe temperature, which reflects the solar radiation; T_w is wet bulb temperature and T_a dry bulb temperature.

For indoor conditions, WBGT was modified to,

$$WBGT = 0.7T_w + 0.3T_a \tag{2}$$

The coefficients in this index have been determined empirically and the index has no physiological correlates. According to Froom et al.[5], WBGT was approved by the ISO (ISO 7243) organization as an international standard in 1982 for heat load assessment, and the index is commonly used as a safety index for workers in various occupations. However, WBGT is limited in evaluating heat stress due to the inconvenience of measuring T_g. Black globe temperature is usually measured by a thermometer surrounded by a 6” blackened sphere.

Lind and Hellon [6] proposed the Oxford index (WD); a simple direct index based on T_w and T_a (Eq. 3).

$$WD = 0.85T_w + 0.15T_a \tag{3}$$

According to a recent study by Parsons [7], though this index is easy to use it was argued that it is not appropriate where there is significant thermal radiation. Because of the easiness to apply the WD, other indices based on the same concept were proposed. Thorn[8] developed an index based only on two parameters (Eq.4).

$$DI = 8.3 + 0.4T_a + 0.4T_w \tag{4}$$

where DI stands for Discomfort Index expressed in Discomfort Units (DU). Sohar et al.[9], adapted the Dl and changed it to a simple average between T_w and T_a (Eq. 5).

$$DI = 0.5T_w + 0.5T_a \tag{5}$$

The DI (Eq 5) was found to be highly correlated to the effective temperature (ET) index [10]. More importantly, the DI correlated to sweat rate both at rest and under exercise, reflecting its physiological significance. The DI values are very similar to those of the WBGT index.

A criterion was established based on a great number of observations on a wide spectrum of population groups and under different climatic conditions, to characterize the environmental heat stress and the correlate thermal sensation (Table 1).

Table 1. Classification of Thermal Sensation using Discomfort Index Values (*Source: Sohar E., 1979 [11]*)

DI (Discomfort units)	Thermal Sensation
Less than 22	No heat stress
2224	Most people feel a mild sensation of heat
2428	People feel very hot, and physical work may be performed with some difficulties
Above 28	The heat load is considered severe, and people engaged in physical work are at increased risk for heat illness

2. Data and Methodology

The study used observed daily dry bulb temperature and wet bulb temperature for the year 2010 from a predetermined stations representing homogeneous zone over Kenya. The stations considered are Dagoretti Corner, Lodwar, Wajir, Kakamega, Kisumu, Nyeri, Narok and Moi International Airport meteorological stations. The data set for the fifteenth (15th) day of each month was used to represent the month. The data was sourced from Kenya Meteorological Department (KMD).

The forecasted values of wet and dry bulb temperatures from Small-Scale Modelling (COSMO) model for five days, 13 17th March 2012 were used to compute DI values that can be derived from the model in the daily weather forecast.

The Consortium for Small-Scale Modelling (COSMO) Model is a non-hydrostatic limited-area atmospheric prediction model. It has been designed for both operational numerical weather prediction (NWP) and various scientific applications. It based on the primitive thermo-hydrodynamical equations describing compressible flow in a moist atmosphere. The model equations are formulated in rotated geographical coordinates and a generalized terrain following height coordinate. A variety of physical processes are taken into account by parameterization schemes. The present operational application of the model within COSMO is mainly on the meso-B scale using a grid spacing of 7 kilometers.

The values of DI were computed by applying Eq. 5.

3. Results

3.1 Discomfort Index Values derived from observed data

The highlands east and west of Rift Valley and Nairobi counties experience no heat stress throughout the year. However, it is notable that the inhabitants of the north eastern, coastal Kenya and north western

Table 2. **Discomfort Index Values using observed data (Year: 2010)**

Station	Month											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Dagoretti	14.5	18.3	15.2	17.3	15.9	15.3	13.9	13.4	14.8	16.9	16.0	16.0
Lowdar	21.8	26.9	25.4	27.1	27.3	25.7	23.8	23.8	24.7	25.8	26.1	23.7
Wajir	23.7	24.5	27.4	25.8	25.4		23.3	23.0	23.5	24.1	24.8	24.4
Kakamega	14.5	19.7	19.3	19.0	19.3	17.5	18.7	18.2	18.4	20.2	19.8	19.1
Narok	12.1	16.6	14.6	17.0	15.3	16.7	13.3	13.3	15.0	18.1	17.4	15.2
Kisumu	18.4	20.7	21.2	20.2	22.9	20.3	20.6	19.2	19.0	22.6	20.6	21.4
Nyeri	12.3	15.8	15.6	18.2	15.9	14.9	12.9	13.3	13.8	17.0	15.7	13.3
Mombasa	25.1											

counties of Kenya represented Lodwar, Mombasa and Wajir feel very hot especially during March May season. This implies that physically, they perform with some difficulties reducing their productivity. The lake region, represented by Kisumu mainly experience no heat stress and mild heat sensation alternately throughout the year (Table 2).

3.2 Discomfort Index derived from forecasted values by COSMO Model

The DI values are slightly higher than those obtained using observed data; the values are however in conformity with DI values for the month of March derived from observed data which are the highest in the year. Discomfort Index values are highest in north eastern and western Kenya counties represented by Wajir and Lodwar respectively. The DI values range between 24 28, in which people feel very hot, and physical work may be performed with some difficulties. Similarly, Nyeri, representing highlands east of Rift Valley and Nairobi area has lowest DI values; in the range of 22 to 24 within which most people feel a mild sensation of heat.

Table 3. **Discomfort Index Values derived from COSMO Model**

	Time				
Station	13/03/12	14/03/12	15/03/13	16/03/13	17/03/13
Dagoretti	24	25	26	25	26
Lodwar	27	28	26	25	26
Wajir	27	28	28	28	29
Kakamega	25	27	27	27	26
Narok	23	25	25	26	25
Kisumu	26	26	27	27	27
Nyeri	22	23	23	23	25
Mombasa	25	26	27	26	26
Makindu	25	25	25	26	26

4. Conclusion and Recommendations

Indeed the effect of temperature on living things cannot be underestimated. Packaging of temperature information in a way that can be easily understood and applied by the end users is therefore key to increasing the value of daily weather forecast. Although DI is simple and easy to use, it does not factor

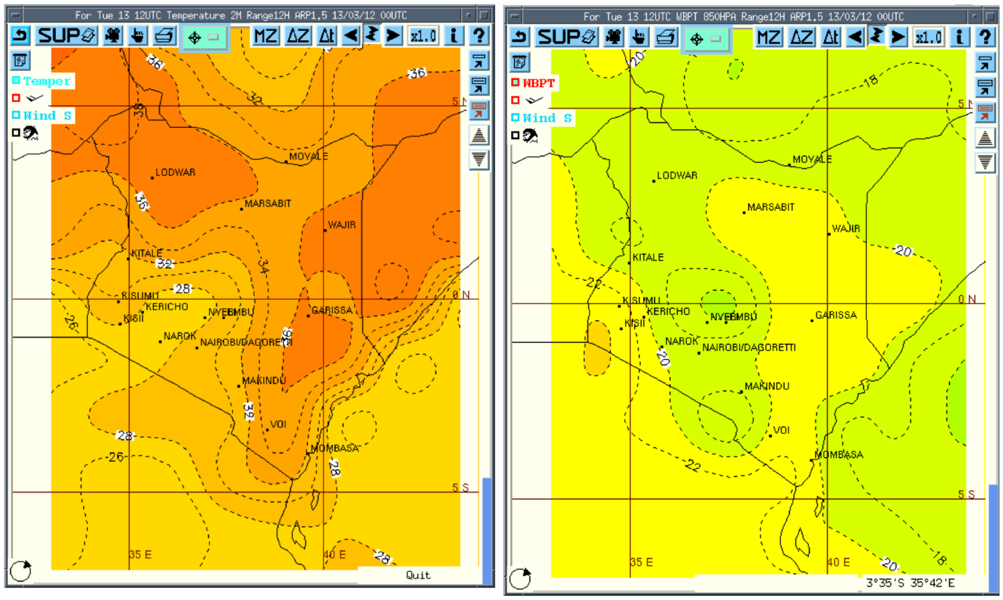

Figure 1. COSMO Model Images showing Dry and Wet Bulb temperatures over Kenya for 13th March 2012: a) Dry Bulb b) Wet Bulb Temperature

some variables, and conditions such as clothing, it was been applicable for almost five decades. The DI is in use in many areas worldwide.

COSMO model gives a relatively good prediction of DI in Kenya. The study thus suggests that KMD adopts this index and tests its applicability in different climatic zones.

Acknowledgments

We thank the administration and staff of Kenya Meteorological Department for support in the provision of data, encouragement and understanding during the study.

References

[1] Y. Epstein and D. S. Moran, "Thermal comfort and the heat stress indices," *Industrial Health*, vol. 44, no. 3, pp. 388–398, 2006.

[2] W. o. . y. Court, A., *Preprint Volume of Extended Abstracts: Fifth Conference on Biometeorology*. American Meteorological Society, 1981.

[3] J. Haidane, "The influence of high temperature," *J. Hyg.*, vol. 5, pp. 404–409, 1905.

[4] Y. CP *et al.*, "Control of heat casualties at military training centers.," *AMA Archives of Industrial Health*, vol. 16, no. 4, pp. 302–316, 1957.

[5] P. Froom, E. Kristal-Boneh, J. Ribak, and Y. Caine, "Predicting increases in skin temperature using heat stress indices and relative humidity in helicopter pilots.," *Israel journal of medical sciences*, vol. 28, no. 8-9, p. 608, 1992.

[6] A. Lind and R. Hellon, "Assessment of physiological severity of hot climates," *Journal of Applied Physiology*, vol. 11, no. 1, pp. 35–40, 1957.

[7] P. K., “Human thermal environments, 2nd ed.,” *Taylor and Francis,London.*, pp. 258–292, 2003.

[8] E. C. Thom, “The discomfort index,” *Weatherwise*, vol. 12, no. 2, pp. 57–61, 1959.

[9] E. Sohar, C. Birenfeld, Y. Shoenfeld, and Y. Shapiro, “Description and forecast of summer climate in physiologically significant terms,” *International Journal of Biometeorology*, vol. 22, no. 2, pp. 75–81, 1978.

[10] E. Sohar, J. Tennenbaum, and N. Robinson, “A comparison of the cumulative discomfort index (cum di) and cumulative effective temperature (cum et), as obtained by meteorological data,” *Biometeorology, Tromp SW (Ed.)*, pp. 395–400, 1962.

[11] E. Sohar, “Man in the desert,” *Arid zone settlement planningthe Israeli experience, Golani G (Ed.)*, pp. 477–518, 1979.