

ASSESSMENT OF THE EFFECT OF URBANIZATION ON THE THERMAL COMFORT
OVER SOME PARTS OF TANZANIA

By

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DECLARATION

This project is my original work and has not been presented for a degree in any other University.

by

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This research project has been submitted for examination with our approval as University Supervisors.

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Acronyms

TC:	Thermal comfort
WBGT	Wet bulb globe temperature
MDI	Modified discomfort Index
DI	Discomfort index.
THI	Temperature humidity index
CI	Climate index
UTCI	Universal Thermal climate index
DAR	Dar es Salaam
ZNZ	Zanzibar
TG	Tanga

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ABSTRACT

The study assessed the effect of urbanization on the thermal comfort over Dar es Salaam, Zanzibar and Tanga. The monthly mean dry bulb temperature, dew point temperature and wind speed for the period of 1980 - 2010 at 0600Z and 1200Z were collected from Tanzania Meteorological Agency (TMA) while the population data was obtained from National Bureau of Statistics. The thermal comfort index was calculated by using Wind Chill Index and Kawamura's Discomfort Index. The temporal and spatial variation of thermal comfort index was determined. The possible association between thermal comfort index and population was also discussed. Result from the study showed that thermal comfort index observed to be high and people feel uncomfortable most of the year except in June, July and August (JJA). The study revealed that thermal comfort index was highest over Tanga and lowest over Dar es Salaam during the month of February at 0600Z while observed to be highest over Zanzibar and lowest over Tanga at 1200Z. In the month of July the highest thermal comfort index was observed over Zanzibar and the lowest indicated over Dar es Salaam at 0600Z while at 1200Z the highest values was observed over Dar es Salaam and lowest over Tanga. The difference in the index values can be attributed to the different bioclimatic condition and topography of the three cities. Population data was correlated with thermal comfort index and was indicated that, weak positive relationship between thermal comfort index and population at morning (0600Z) and weak negative relationship at afternoon (1200Z). However, the study showed no significant relationship in population data and thermal comfort index. The growth of thermal discomfort index in three cities is driven highly by the continuous increase of buildings, paved roads, buses as well as the decrease of cultivated land rather than population.

CHAPTER ONE

1.0 INTRODUCTION

The atmospheric environment plays a dominant role in the life of all plants and land animals. Preservation of stability in the human body in relation to the atmospheric environment by physiological or technological adjustments is essential for human survival in many parts of the Earth (Lundeberg 1981). All humans are warm-blooded and heat regulation is essential for survival by maintaining a core temperature of about 37°C. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. It is affected by heat conduction, convection, radiation, and evaporative heat loss (Fanger 1972)

In the last 30 years, studies concerning the influence of environmental factors on humans in East Africa countries such as Kenya have been done and some published (Ng'ang'a and Ngugi 1986). and concluded that the Physiological heat stress experienced by a person is determined by both meteorological and non- meteorological factors,

Six major factors that determine comfort are ambient air temperature, humidity, radiation, air movement, intrinsic clothing and level of activity. Other factors that may have some effect on thermal comfort are age, sex, body shape, state of health, ethnic grouping, diet, sleep, color of clothing, acclimatization, availability of fresh air, transients, color of a space enclosure and noise. An indication of the relative importance of these other factors is the fact that when all the six major factors are within an acceptable and optimal range, about 70% of the population will be comfortable (Ogunsote, 2011).

To make research on the subject easier and more comprehensive a lot of bio-climatologically indices have been proposed. Buttner (1938) recognised that in order to assess the thermal

influence of the environment on the human body, the integrated effects of all the thermal parameters had to be taken into account. Since then a lot of researches on indoor and outdoor human thermal comfort have been carried out by many researchers some of whom have put forward bioclimatology indices such as as Thom (1959), Lally and Watson (1960), Givoni (1963), Kawamura(1965),Fagner (1970), Masterson and Richardson (1979), Wintering (1979), Jendritzky and Nübler (1981), Kalkstein (1982), Weiss (1983) and Steadman (1984).

1.1 Problem statement

Rapid urbanization process and climate change continue to put great pressure on the environment, leading to increases in climatic stress and weather related disasters (Ogunsote, 2011). This results to thermal stress which affects the productivity and wealth of individual and diminishes tolerance.

Stressed areas can results in health problems and reduce performance of operation. Feeling of uneasy, dimness of the vision, heaviness of the head, dullness of hearing, torpor and languor, hardness of abnormal reactions are among others that human body experiences due to the heat stress caused by temperature (Lowry 1992).

1.2 Objectives of study

The main objective of the study is to assess the thermal comfort in three urban cities in Tanzania. The specific objectives of this study include the following.

- (i) To determine temporal variability of thermal comfort of urban Dar es Salaam, Zanzibar and Tanga.
- (ii) To determine spatial variability of thermal comfort in Dar es Salaam, Zanzibar and Tanga.
- (iii) To determine the relationship between population and thermal comfort index in Dar es Salaam, Zanzibar and Tanga.

1.3 Justification of study

Thermal comfort is very important in human biometeorology. It affects the productivity and the health of the individual and diminishes tolerance to other environmental hazards. Thermal comfort is an important indicator for the assessment of life quality within cities. It is strongly influenced by city climate conditions present in urban ecosystems. The quality of urban open spaces, closely related to thermal conditions, can contribute to the quality of life within cities or, on the contrary, enhance isolation and social exclusion. Both are related with the thermal physical and social environment. (Woolner, 2006).

Therefore in order to increase the functionality and good use of outdoor space, following the idea of revitalizing the cities, the environmental conditions and thermal comfort are strong factors that affect the quality of human habitat inside cities.

1.4 Hypotheses of study

In this study, the hypothesis is stated that if changes in weather parameters are extreme, then thermal stress will increase in urban cities

1.5 Area of study



Map of Tanzania

Source: <https://www.google.com/> blank map of Tanzania,(2013)

DAR ES SALAAM

The City of Dar es Salaam is the largest city in Tanzania. It is also the country's richest city and a regionally important economic centre. The city of Dar es Salaam is located within the Dar es Salaam Region with total surface area of total area of 1,400 km² and a population of 4,364,541 as of the official 2012 census.

Being situated so close to the equator and the warm Indian ocean, the city experiences generally tropical climatic conditions, typified by hot and humid weather throughout much of the year. Dar es Salaam features a tropical wet and dry climate, with two different rainy seasons: "the long rains, which fall during April and May, and "the short rains", which fall during October and November.

TANGA

Tanga region is located in the northeastern side of Tanzania Mainland. The region lies between latitudes 4° and 6° south of the Equator, and between longitudes 37° and 39° east of Greenwich. The Region is bordered by the Republic of Kenya in the north, Kilimanjaro Region in the northwest, Manyara Region in the west, Morogoro and Coast Regions in the south and the Indian Ocean in the east. Tanga Region has a total area of about 27,342 km² with population of 2,045,205

The dominant climate in Tanga Region is warm and wet. It is found along the coast and in the inland with two different rainy seasons: "the long rains, which fall during April and May, and "the short rains", which fall during October and November.

ZANZIBAR

Zanzibar is an Island in Indian Ocean of an area of 1530Km² with population of about 1000000 located between 4°40' and 6°30' south and longitude 39° and 40°E. It is situated at 60km off the Eastern coast of Tanzania mainland. The climate of Zanzibar is hot humid with two rainfall seasons. Long rain season which occurs from March to May and short rains season received from September to December.

CHAPTER TWO

2.0 LITERATURE REVIEW

Thermal comfort (TC) is defined as ‘that condition of mind which expresses satisfaction with the thermal environment’ (ASHRAE 1966; Fanger 1972; Parsons 2003; ISO7730 2005) and no preference to be warmer or cooler. (Fanger 1972). Workers, soldiers, and travelers are often exposed to severe environmental heat stress, which may deteriorate work efficiency and productivity and may even threaten survival. It is thus expected that the physiological heat strain experienced by an individual will be related to the total heat stress to which he is exposed, serving the need to maintain body-core temperature within a relatively narrow range of temperatures. Many attempts have been made to estimate the stress inflicted by a wide range of work conditions and climate, or to estimate the corresponding physiological strain and to combine them into a single index, a heat stress index.

An essential requirement for continued normal body function is that the deep body temperature will be maintained within a very narrow limit of $\pm 1^{\circ}\text{C}$ around the acceptable resting body core temperature of 37°C . To achieve this, body temperature equilibrium requires a constant exchange of heat between the body and the environment. The rate and amount of the heat exchanged is governed by the fundamental laws of thermodynamics. In general terms, the amount of heat that must be exchanged is a function of:

- a) The total metabolic heat produced, which for a 70 kg young male, may range from about 80 watts at rest to about 500 watts for moderately hard industrial work (and up to 1,400 watts for a very trained endurance athlete);
- b) The heat gained from the environment (≈ 17.5 watt per change of 1°C in ambient temperature, above or below 36°C). The amount of heat that can be exchanged is a function of sweat evaporation (≈ 18.6 watt per 1 mmHg change in ambient vapor pressure, below 42 mmHg (assuming a mean skin temperature of 36°C) (Moran, 2006)

In (1970) Fanger defined three parameters for a person to be in thermal comfort:

- a) The body is in heat balance;
- b) sweat rate is within comfort limits;
- c) Mean skin temperature is within comfort limits.

These conceptual requisites for determining thermal comfort can be expressed by measurable terms as: body-core temperature within a very narrow range of 36.5–37.5°C, a skin temperature of 30°C at the extremities and 34–35°C at body stem and head, and the body will be free of sweating.

In 1957, Yaglou and Minard developed the WBGT as a thermal index calculated as follows:

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

Where T_w is wet bulb temperature

T_g is black globe temperature

T_a is ambient temperature.

This index has been in extensive use for evaluating environmental heat stress in the U.S.

Army, sport activities and as safety guidance for workers in different occupations. However, WBGT was found to be limited in evaluating heat stress mainly due to the inconvenience of measuring T_g , the corrections needed for different clothing (e.g., protective clothing) and for various metabolic rates .

Therefore, D.S. Moran *et al in* 1998 carried out a research to determine whether the newly developed modified discomfort index (MDI) calculated as

$\text{MDI} = 0.30T_a + 0.75T_w$ could be used as an alternative for WBGT. They used data from three different countries, USA, Egypt, and Israel. Measurements of the meteorological parameters to calculate WBGT and MDI were done using the same thermometers. T_a was measured using a mercury- in-glass thermometer, T_w was measured using a naturally aspirated wet bulb and T_g was measured using the Vernon black globe thermometer. In addition, wind speed at 1.2m above

ground level and total hemispheric radiation levels were measured in Egypt and in Israel. Evaluations and comparisons of WBGT and MDI were done and they depicted highly significant correlations. Even though these two indices depicted a high correlation, the use of MDI instead of WBGT was accurate for USA only. In Egypt and Israel, MDI underestimated WBGT. Hence there was need to use a regional correction factor together with the MDI in order to get accurate results. Thus this research concluded that the MDI, obtained only from T_a and T_w can only be used as a simple tool for measuring thermal load. However, in order to use it as a substitute for WBGT a regional correction might be needed according to the latitude studied.

In 1979, R. G. Steadman published a new temperature–humidity index based on several previous biometeorological studies (Steadman 1979). This index, unlike the previous DI, indicated the apparent temperature that a person would feel relative to a “normal” humidity corresponding to a dew point of 14°C . The model that Steadman created was based on five sub models, some of which had been empirically obtained. He also identified numerous parameters such as a person’s build, activity, and clothing along with solar radiation and effective wind speed, all of which influenced a person’s perception of apparent temperature. In 1984 Steadman refined his model and included the effect of wind chill to produce a “universal scale of apparent temperature” (Steadman 1984). This scale was presented in the form of four tables; one primarily tabulating apparent temperatures at lower temperatures taking wind speed into account, another primarily considering the effect of humidity on higher temperatures, and two taking into account the incremental warming due to full sunshine. For meteorological reporting purposes, the effect of full sunshine was of limited utility since the exposure to sunshine varied from person to person. The remaining factors: wind chill at lower temperatures and the THI at higher temperatures were regularly reported, and became familiar to much of the public. In 2001, the National Weather Service (NWS) adopted a new model for the wind chill factor, but it retained Steadman’s model for the THI.

In 1986 Nganga and Ngugi carried out a research using the Discomfort Index to determine the Physiological comfort indices for different parts of Kenya and concluded that the Physiological heat stress experienced by a person is determined by both meteorological and non-meteorological factors, (Ng’ang’a and Ngugi 1986).

In 1999 S. Becker et al examined the climatic conditions of 31 cities and resorts in South Africa with regard to the thermal perception of people. The evaluation of the thermal conditions was based on the human energy balance calculations, which had been specified for the detection of hot or cold discomfort of people walking outdoors in spite of adapted clothing. Hot days and cold days were defined depending on the extent and duration of thermal discomfort. Cities were rated according to the Climate Index (CI), which was defined in terms of the monthly frequency of hot or cold days. The most pleasant conditions in the annual average were found along the coastal belt (Port St. Johns, Richards Bay, St. Lucia) and the most unpleasant ones in the Mediterranean region around Cape Town, the Karoo and the eastern lowveld.

In 1999 International Society of Biometeorology realized that most of the thermal indices did not relationships with physiological reactions in man. Therefore, it established special study group to develop new Universal Thermal Climate Index (UTCI). Since 2005 these efforts have been reinforced by the COST Action 730 (Cooperation in Science and Technical Development). In February 2009 the Action was terminated and UTCI was developed. The new UTCI index represents air temperature of the reference condition with the same physiological response as the actual condition. The index base on Fiala model that is one of the most advanced multi-node thermophysiological models and include the capability to predict both whole body thermal effects (hypothermia and hyperthermia; heat and cold discomfort), and local effects (facial, hands and feet cooling and frostbite). The index can be applied in various research, including weather forecasts, bioclimatological assessments, bioclimatic mapping in all scales (from micro to macro), urban design, engineering of outdoor spaces, consultancy for where to live, outdoor recreation and climatotherapy, epidemiology and climate impact research. An example of such research is the thermophysiological principles of UTCI as well as some examples of its application to assess bioclimatic differentiation of Europe by Krzysztof, *et al* in 2010.

In 2011 Robaa carried out detailed studies on the effect of urbanization and industrialization processes on outdoor thermal human comfort in Greater Cairo region. Four different districts in Greater Cairo region were selected to represent rural, suburban, typical urban and industrial areas. The data of surface dry, wet bulb temperatures and wind speed for two different periods representing non-urbanized and urbanized periods were used. Discomfort indices for the two periods were calculated for the four districts. The study revealed that urbanization and industrialization processes have resulted in the distinctly modification of human comfortable at

all districts. The feeling of quite comfortable reduced from the old non-urbanized period to the recent urbanized period at the four districts. During the recent urbanized period, the rural area had the highest total number of quite comfortable hours while both urban and industrial areas had the lowest total number of hours. The serious hot uncomfortable didn't occur at all districts during the old non-urbanized period while during the recent urbanized period, all people had felt extreme serious hot uncomfortable only at urban and industrial areas. It could be concluded that the urbanization and industrialization processes caused increase of human serious hot uncomfortable feeling which in turn leads to more hindering for the human activities while the rural conditions leads to optimum weather comfort for further and more human activities.

The new formula was tested on human subjects in the chilled wind tunnel at Canada's Defence Civil Institute of Environmental Medicine in Toronto during the summer of 2000. In the wind tunnel, the faces of six men and six women were exposed to various combinations of temperature and wind speed, and the rate of temperature drop of the exposed skin was measured and their assessment of the "feel" of the cold recorded. Specifically, the new **Windchill Temperature Index** is :-

$$T_w = 13.112 + 0.6215T_a - 11.37V^{0.16} + 0.3965T_aV^{0.16}$$

Where

T_w is the wind chill, V is the wind speed in kilometers per hour, and T_a is the ambient air temperature in degree Celsius.

Techniques like these have been applied in many different tropical areas that have nearly the same climatic characteristic like the coast of Tanzania. Some of them are Bombay, Assam as well as Indonesia.

CHAPTER THREE

3.0 DATA AND METHODOLOGY

3.1 Data

The monthly mean dry bulb temperature, dew point temperature and wind speed were collected from Tanzania Meteorological Agency (TMA).

The following two sets of data from three meteorological stations, Dar es Salaam, Tanga and Zanzibar were used. These covered a period of 31 years (1980 - 2010.)

- (i) Long term monthly mean dew point temperature for 0600GMT and 1200GMT.
- (ii) Long term monthly mean Dry Bulb temperature for 0600GMT and 1200GMT.
- (iii) The population of Dar es Salaam, Zanzibar and Tanga. in Tanzania from 1978 -2012. was collected from National Bureau of Statistics.

3.2 Data quality control

The quality of meteorological data is critical in any type of research. The quality of data rests on the accuracy of measurements and completeness. Quality control will ensure that meteorological data acquired meets certain standards. It will involve estimating missing data, looking for errors in the acquired data and possibly removing mistakes from it, and testing for data in homogeneity or inconsistency.

3.3 Estimating missing data.

If the data to be used will have any missing gaps, then the gaps will be filled using the arithmetic mean method to ensure that data analysis is up to date.

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n x_i \dots\dots\dots 1$$

Where;

\bar{X} Is the long term mean air temperatures.

n Is the number of years.

3.4 Data homogeneity

Data inhomogeneity can arise due to changes in observational schedules and methods, instrumental changes, changes of exposure conditions, shifting of station sites, and other human processes (WMO, 1996). The test that I will use to check for data consistency is the single mass curve. This is a plot of cumulative data for a given location against time. The data is accumulated backwards in time. The single mass curve detects data inconsistency and provides a corrective measure for these inconsistencies.

3.5 Model equation

In the present study, the bioclimatic index most commonly used in urban climate studies to describe the level of thermal sensation that a person experiences due to the modified climatic conditions of an urban area. Kawamura’s Discomfort Index [DIK] (KAWAMURA, 1965) which uses air temperature and dew point temperature and Wind chill Index which uses air temperature and wind speed (10m) were applied

3.5.1. Kawamura’s Discomfort Index [DIK] (KAWAMURA, 1965)

$$DI_k = 0.99 * T_a + 0.36 * T_d + 41.5 \dots\dots\dots 2$$

Where by

T_a is the hourly value of the mean air temperature (°C)

T_d is the hourly value of the mean dew point temperature (°C)

The following condition will be used to define the level of discomfort.

Table 1. *Values of Kawamura’s Discomfort Index calculated for Celsius temperature scales.*

DI_k (°C)	Interpretation
>80	Unbearably hot
75-80	Uncomfortably hot
60-75	Comfortable
55-60	Uncomfortably cold
<55	Unbearably cold

3.5.2. Wind chill Index

$$T_{wc} = 13.12 + 0.6215T_a - 11.37V^{+0.16} + 0.3965T_aV^{+0.16} \dots\dots\dots 3$$

Where by

T_a is the hourly value of the mean air temperature ($^{\circ}c$)

V is wind speed (km/h)

Table 2. *Values of Wind Chill Index*

DI_w	Interpretation
> 43	Very hot
31 - 43	Hot
26 – 31	Warm
18 - 26	Neutral
12 - 18	Cool
4 - 12	Cold
< 4	Very cold

3.6 Trend analysis

Trend is the long term movement in a time series. Examination of the trend component in any time series analysis is significant since it will show whether the time series is stationary or non stationary. Trend can be linear or non linear, and the objective approach to examine this is through graphical and statistical approach (WMO 1996). The graph of the time series will indicate whether or not a linear relationship will provide good approximation to the long term movement, regression analysis may give the curve of the best fit. Graphical and statistical method will be applied to examine trend.

3.7 Spatial analysis

The graph of comfort indices against the corresponding stations will be plotted. Therefore the variation of the comfort index from one city to another will be known.

3.8 Correlation Analysis

This method provides the degree of relationship between variables. The correlation coefficient r is a measure of the linear relationship between two attributes or columns of data. The correlation coefficient is also known as the Pearson product-moment correlation coefficient. The value of r can range from -1 to +1 and is independent of the units of measurement. A value of r near 0 indicates little correlation between attributes; a value near +1 or -1 indicates a high level of correlation. Simple correlation coefficient r between thermal comfort index and population data will be calculated. The value of r will be evaluated using Equation 3.

Simple correlation will be used to determine the degree of relationship between any pair of variables. The simple correlation coefficient between variable X and Variable Y is given by the formula;

$$r = \frac{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 (y_i - \bar{y})^2}} \dots\dots\dots 4)$$

Where; r_{xy} is the correlation coefficient.

n is the sample size.

X_i and Y_i are the variables being correlated.

\bar{x} and \bar{y} are the mean values of variables being correlated.

n is the number of data points used

The computed correlation values will be tested for statistical significance at 95% confidence level using the student-t- test as shown in the formula below;

$$t_{n-2} = r \sqrt{\frac{n-2}{1-r^2}} \dots\dots\dots 5$$

Where; t- is the value of the student-t-test

n - is the number of observations

r - is the correlation being tested

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

The section outlines the results and discussions from the analysis.

4.1 Results from Data Quality Control

4.1.1 Missing data

Missing dry bulb temperature, dewpoint temperature and wind speed records were encountered from three stations, all stations had data missing. Simple arithmetic mean method was used to estimate for missing data.

4.1.2 Test for Data Homogeneity.

The test for homogeneity was done for all stations. The single mass curve, which is a plot of annual cumulative values of meteorological parameters against time was used to test for homogeneity. R showed the goodness of fit of the points. The trend line had no breakage on the time for all the stations used in the study thus indicating homogeneity. Figure 1,2 and 3 below show some of single mass curves for three stations.

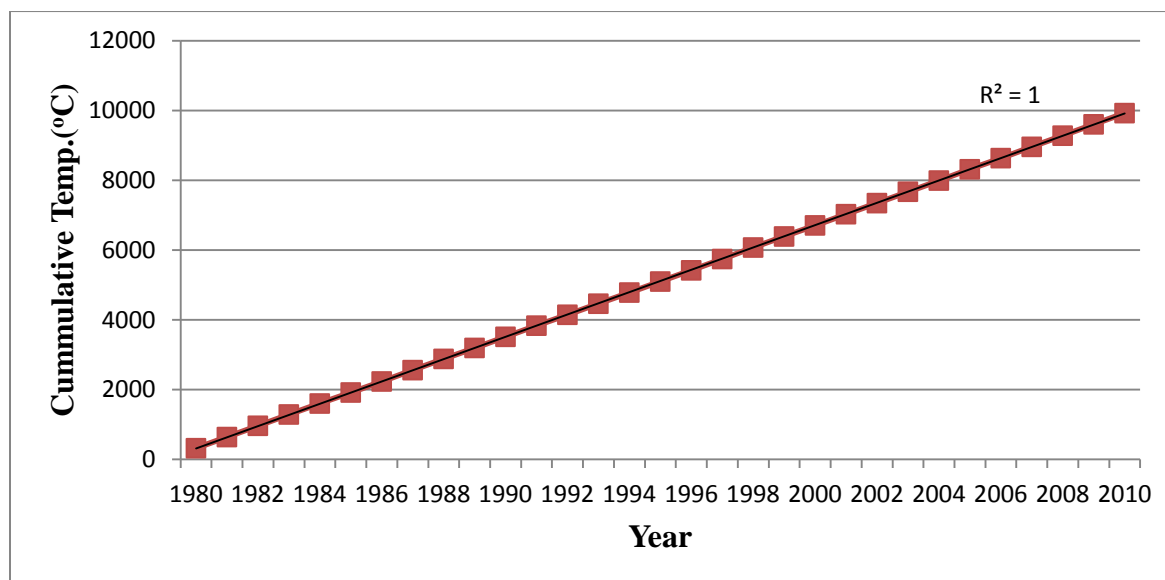


Fig. 1: Zanzibar Single mass curve for 0600Z dry bulb temperature.(1980-2010)

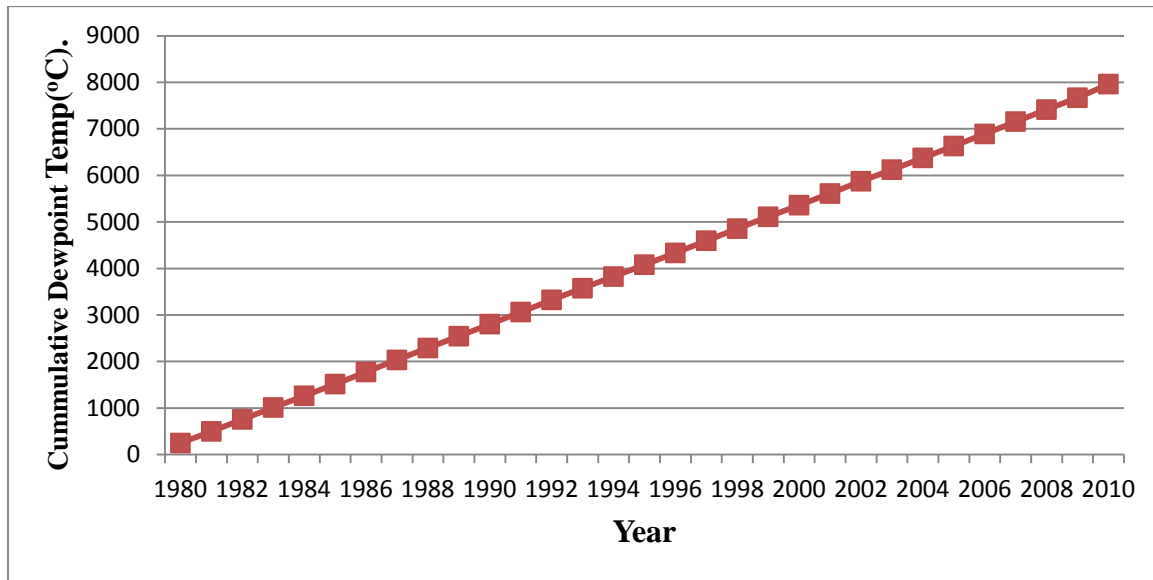


Fig 2: Dar es salaam single mass curve for 1200z dew point temperature.(1980-2010)

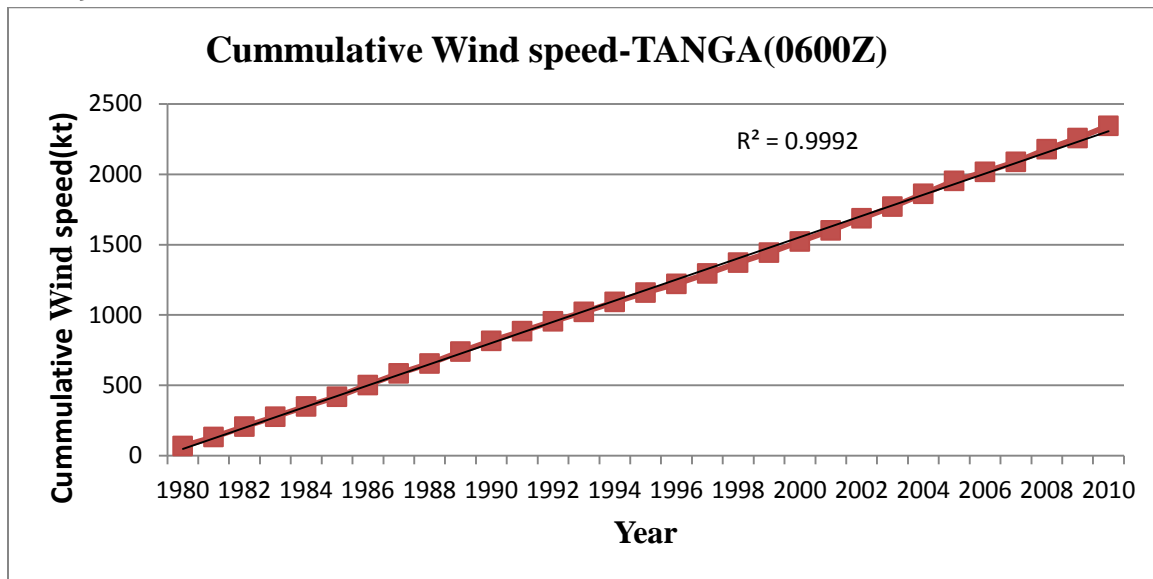


Fig.3: Tanga single mass curve for 0660z (1980-2010)

4.2 THERMAL COMFORT INDEX VALUES

Kawamura's Discomfort Index [DIK] values

The variation of the Kawamura's Discomfort index at different months for Dar es Salaam, Zanzibar and Tanga are displayed in the tables 1, 2 and 3 respectively.

Table1: Monthly variation Kawamura's Discomfort Index for Dar es Salaam

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0600Z	78	78	77	76	75	73	72	73	74	76	78	78
1200Z	80	81	80	79	78	77	76	76	77	79	79	80

Table 2: Monthly variation of Kawamura's Discomfort Index for Zanzibar

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0600Z	78	78	78	77	76	74	73	73	74	76	78	78
1200Z	81	81	81	79	78	77	76	77	78	79	79	80

Table 3: Monthly variation of the Kawamura's Discomfort Index for Tanga.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0600Z	78	79	79	78	76	75	74	74	75	77	78	79
1200Z	80	81	81	80	78	77	76	76	77	78	80	80

WIND CHILL INDEX VALUES

Table 4: Monthly variation of Wind Chill Index for Dar es Salaam.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0600Z	30	30	29	28	27	25	24	25	27	29	30	30
1200Z	34	34	33	31	31	31	30	31	32	33	33	33

Table 5: Monthly variation of Wind Chill Index for Zanzibar

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0600Z	30	31	30	29	28	26	26	26	27	29	30	31
1200Z	34	35	34	32	31	30	30	30	32	33	32	33

Table 6: Monthly variation of Wind Chill Index for Tanga

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0600Z	30	31	31	29	28	27	25	26	27	29	30	31
1200Z	33	34	35	33	31	30	30	30	31	32	33	33

4.3 DISCUSSION

4.3.1 MONTHLY VARIATION OF THERMAL COMFORT INDEX

Kawamura's Discomfort Index

Table 1: shows that people from Dar es Salaam suffer from hot stress most of the year. The variation of the Thermal comfort Index over Dar es Salaam shows that in all the months, at 1200Z is the most uncomfortable time when people experience the highest hot stress. At 0600Z, all the months are uncomfortable and People suffer from hot stress throughout the year except in the month of June, July August and September. The highest discomfort is experienced in the months of December to February when the index is 78 while the highest comfortable is experienced during the months of July. When the index is 72. At 1200Z, all the months are uncomfortable with hot stress. The highest discomfort (Unbearably hot) is experienced in the February when the index is 81. The hot stress during the month of February is caused by the high humid and temperature while during the month of July, temperature observed to be low with strong dry wind.

Table 2 shows that people from Zanzibar also suffer from hot stress most of the year. The variation of the Thermal comfort Index over Zanzibar shows that in all the months 1200Z is the most uncomfortable time when people experience the highest hot stress. At 0600Z, all the months are uncomfortable and People suffer from hot stress throughout the year except in the month of June, July August and September. The highest discomfort is experienced in the months of November, December January, February and March when the index is 78 while the most people are comfortable in the month of June, July and August When the index is 73.

At 1200Z, all the months are uncomfortable with hot stress. The highest discomfort (Unbearably hot) is experienced in the January, February and March when the index is 81.

Table 3: shows that at 0600Z, all the months are uncomfortable and People suffer from hot stress throughout the year except in the month of July and August where the lowest discomfort index is observed which is 74. At 1200Z all the people from Tanga feel unbearably hot throughout the

year. The highest discomfort is experienced in the months of February and March when the index is 81.

Wind Chill Index

Table 4: shows that people in Dar es Salaam feel warm condition most of the year. The variation of the Wind Chill Index shows that the least values observed in the months of June, July and August at 0600Z which imply neutral condition (comfortable condition). The lowest discomfort value is 24 in July. While at 1200Z people feel uncomfortable due to hot stress where the highest discomfort Index experienced in the months of January and February which is 34. The stress in January and February caused by the high temperature, humidity and light wind.

Table 5. Shows that people Zanzibar suffer from hot stress most of the year. At 0600Z neutral condition (comfortable) experienced only in June, July and August with discomfort value of 26. While the warm condition is experienced in the rest of the months and the highest discomfort value is 31 in the month of December and February. At 1200Z all the people feel hot throughout the year except in the month of the June, July and August where warm condition is experienced with discomfort index of 30 while the highest value of discomfort Index is 35 in the month of February.

Table 6. shows that people in Tanga feel comfortable (neutral condition) in the month of July and August at 0600Z and uncomfortable (warm condition) in the rest of the year. The lowest discomfort value is 25 in July and the highest is 31 in December, February and March. At 1200Z all the people suffer from hot stress in most of the year and feel uncomfortable due to warm condition in June, July, August and September. The highest discomfort index is 35 in March and the lowest is 30 in June, July and August.

4.3.2 GRAPHICAL ANALYSIS

The monthly variations of the thermal Comfort indices for Dar esa Salaam, Zanzibar and Tanga are shown in figure 7 to 12.

Variation of thermal comfort index over all three stations Zanzibar, Dares Salaam and Tanga almost behave the same during a day. Most comfort condition was experienced in June, July and August (JJA) while the highest level experienced in October, November and December (OND) and January, February (JF) as well as March, April and May (MAM). During these seasons the temperature and humidity was high with slight wind compare to the months of June, July and August where the temperature and humidity was low with strong wind speed. However the maximum discomfort index was observed in February while the minimum discomfort index was observed in July during both morning (0600Z) and afternoon (1200Z).

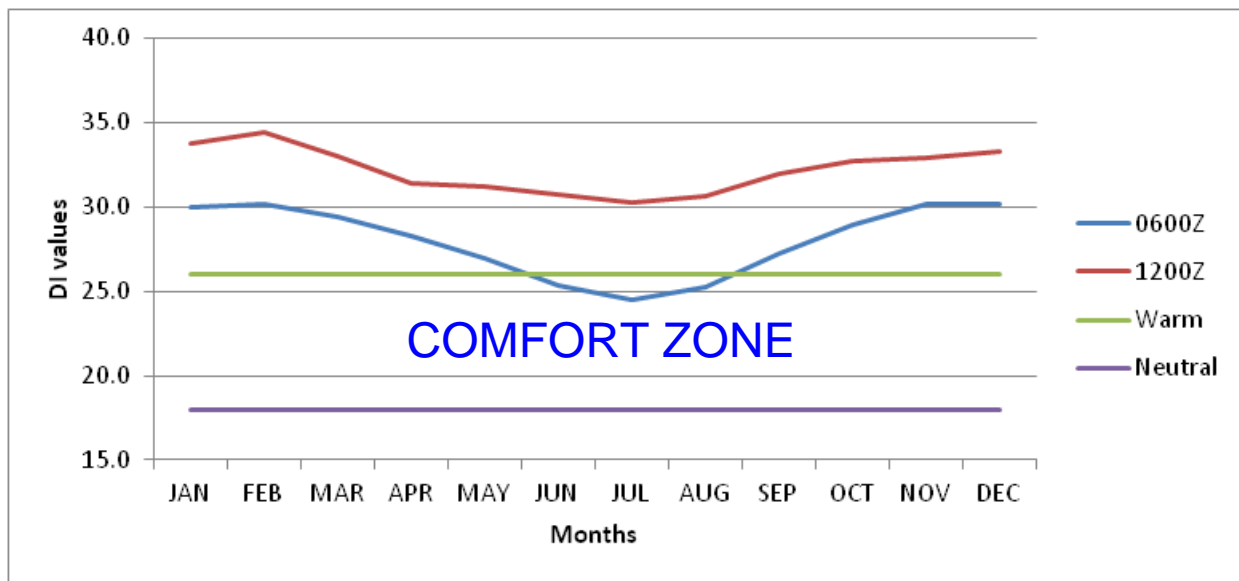


Figure 7: Monthly variation of Thermal comfort index (Wind chill index) for Dar es salaam

All the months are uncomfortable throughout the day and people suffer from hot stress except in the months of June, July and August (JJA) in the morning when comfort is experienced. The highest hot stress is experienced at 1200Z.

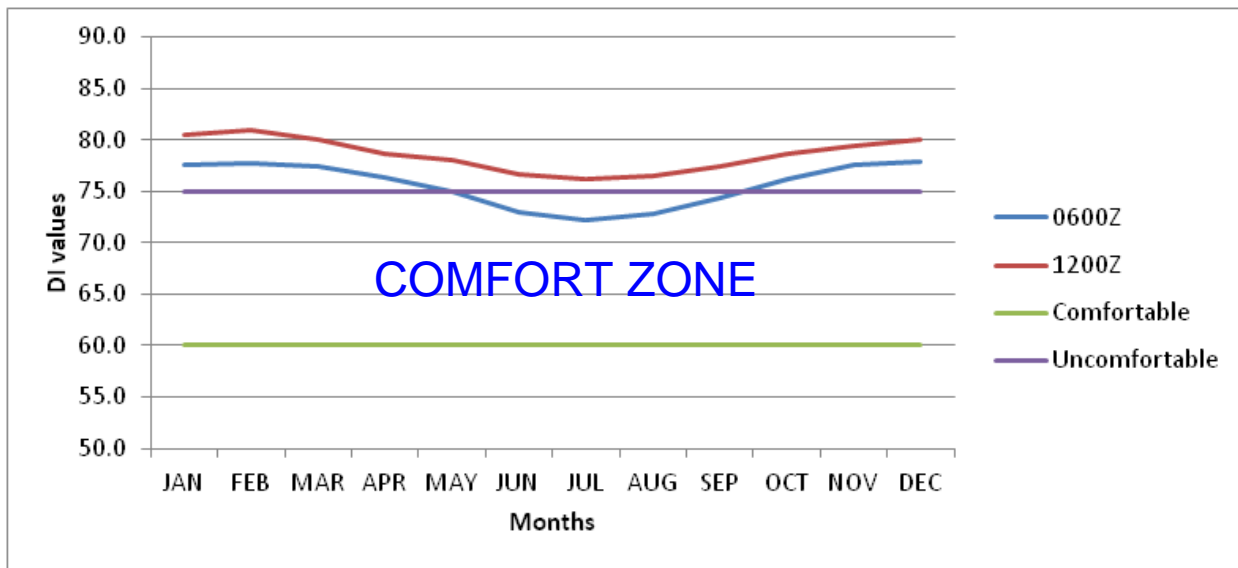


Figure 8: Monthly variation of thermal comfort index (Kawamura's index) for Dar es salaam.

All the months are uncomfortable throughout the day and people suffer from hot stress except in the months of May, June, July, August and September in morning hours. The lowest hot stress is experienced at 0600Z.

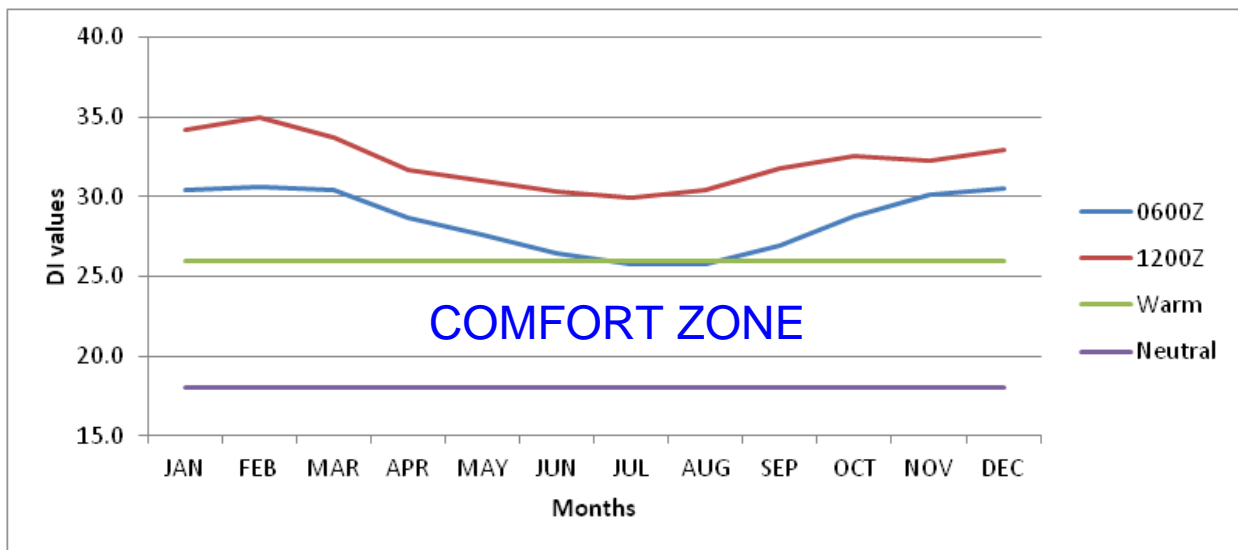


Figure 9: Monthly variation of thermal comfort index (Wind chill index) for Zanzibar

All the months are uncomfortable throughout the day and people suffer from hot stress except in the months of July and August when slight comfort is experienced. The highest hot stress is experienced at 1200Z in February.

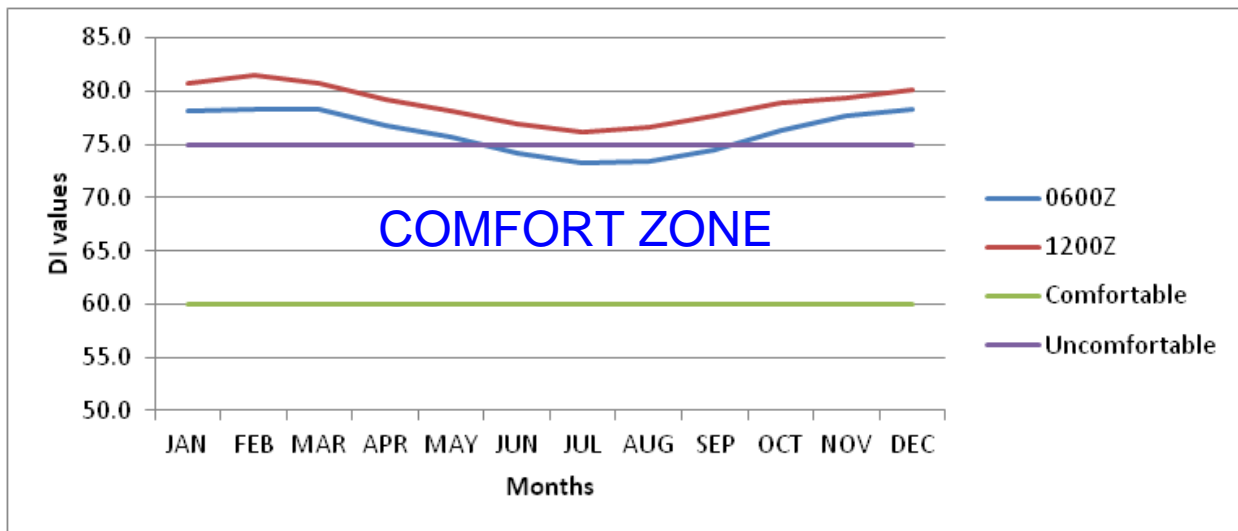


Figure 10: Monthly variation of thermal comfort index (Kawamura's index) for Zanzibar

All the months are uncomfortable throughout the day and people suffer from hot stress except in the months of June, July, August and September when comfort is experienced. The highest level of comfort is experienced at 0600Z in July.

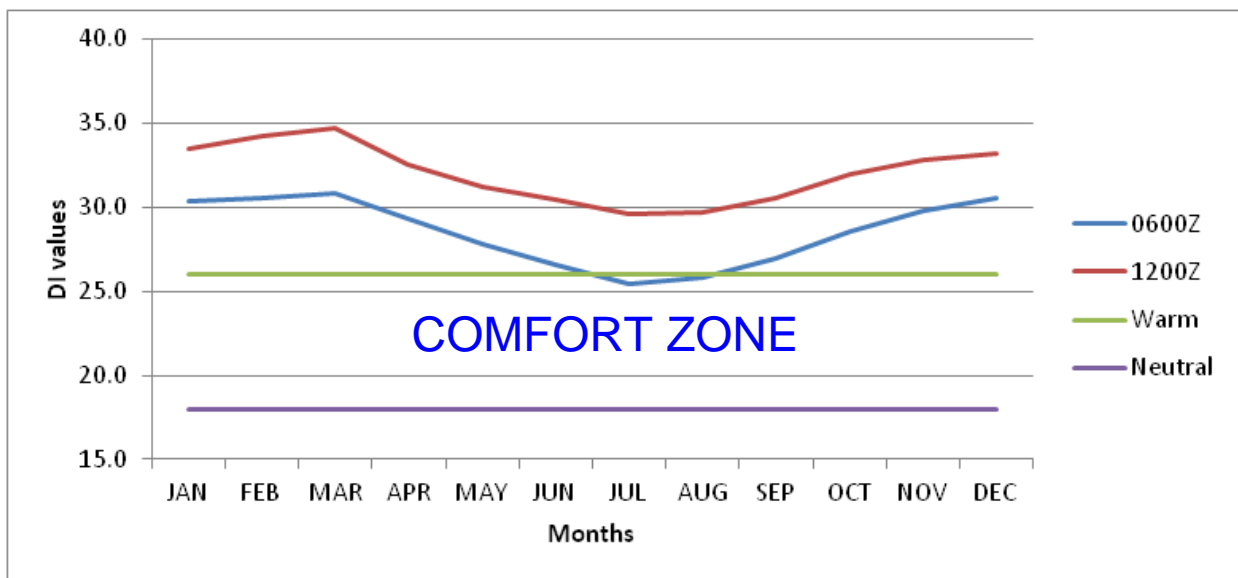


Figure 11: Monthly variation of thermal comfort index (Wind chill index) for Tanga.

All the months are uncomfortable throughout the day and people suffer from hot stress except in the months of July and August when slight comfort is experienced. The highest hot stress is experienced at 1200Z in February.

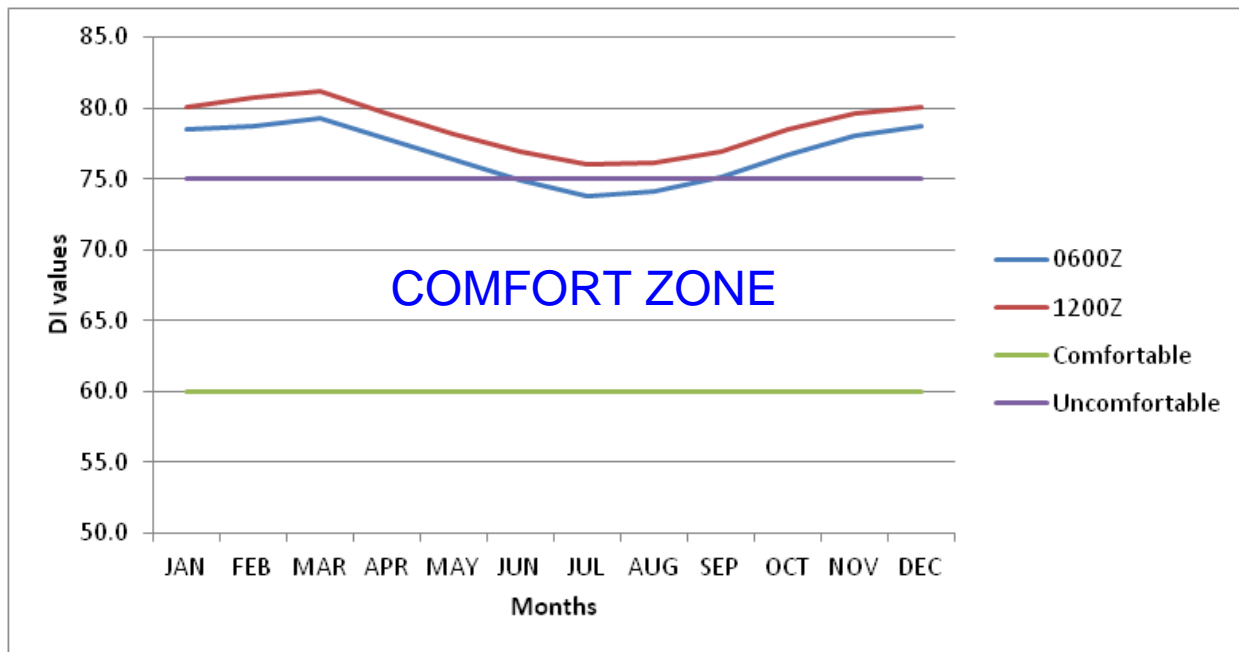


Figure 12: Monthly variation of thermal comfort index (Kawamura's index) for Tanga

All the months are uncomfortable throughout the day and people suffer from hot stress except in the months of June, July, August and September when comfort is experienced. The highest level of comfort is experienced in July at 0600Z while discomfort in February at 1200Z.

4.3.2 Correlation Analysis

The thermal comfort indices values from both Kawamura's Discomfort Index and Wind Chill Index at 0600Z and 1200Z for the months of February and July were subjected to correlation analysis using annual data. 95% Confidence interval was used to test the significance of the correlation coefficient. The correlation coefficient values were taken as significant if the t computed was greater than the t -tabulated at the degree of freedom $v = n-2$, t -tabulated was 2.045. Therefore it was found that thermal comfort indices that are Kawamura's Discomfort Index and Wind Chill Index gave statistically significant correlation coefficient between them.

Table 7: Correlation Coefficient Values.**DAR ES SALAAM - FEB**

	Dw 0600Z	t-test	Dw 1200Z	t-test	t-tab
Dk 0600Z	0.916976	12.4			2.045
Dk 1200Z			0.920005	12.6	2.045
ZANZIBAR- FEB					
Dk 0600Z	0.898283	11.01			2.045
Dk 1200Z			0.870485	8.29	2.045
TANGA - FEB					
Dk 0600Z	0.419044	2.485			2.045
Dk 1200Z			0.905998	11.53	2.045

DAR ES SALAAM - JULY

	Dw 0600Z	t-test	Dw 1200Z	t-test	t-tab
Dk 0600Z	0.916976	12.4			2.045
Dk 1200Z			0.920005	12.6	2.045
ZANZIBAR- JULY					
Dk 0600Z	0.909826	11.81			2.045
Dk 1200Z			0.849245	8.66	2.045
TANGA - JULY					
Dk 0600Z	0.596119	3.998			2.045
Dk 1200Z			0.905998	11.52	2.045

4.3.3 Trend Analysis (Graphical Analysis)

The fluctuations and trends of annual values of thermal comfort indices for the months of February and July have been determined. Variations and trends have been analyzed during the last 31 years period.(1980-2010) as shown in figure 13 to

Dar es Salaam thermal comfort indices indicated a generally increasing trend (positive) at 0600Z and decreasing trend (negative) at 1200Z. While Zanzibar thermal comfort index values

indicated a generally increasing trend at 1200Z and decreasing trend at 0600Z. Tanga thermal comfort indices values indicated a generally increasing trend at both 0600Z and 1200Z.

At the beginning of observing period in 1980s thermal comfort index values for the month of February showed warm period in morning hours and hot condition during the afternoon at all stations followed by cooling period until 1985.

From 1985 warming condition was rising to level of hot condition until the end of 1989s before it was falling until the early 1990s. At the mid 1990s thermal comfort index again was rising before was reached at higher level when indicated as hot condition at the early and mid 2000s.

The trend of thermal comfort indices values for the month of July have plotted as shown from figure 19 to 25.

In July, thermal comfort indices indicated a generally increasing trend (positive) at 0600Z and at 1200Z at all stations.

From 1980s to 2010s thermal comfort indices were shown neutral condition which means comfortable condition over Dar es Salaam station at 0600Z. At 1200Z warm condition was experienced from 1980s until 1991 before was falling to neutral when thermal comfort index decreased sharply in 1992s. From 1993s thermal comfort indices values were rising to warm condition until 2010.

At 0600Z neutral condition was experienced at the beginning of observing period in 1980s over Zanzibar station and thermal comfort indices were rising to warm condition from 1982 to 1983. From 1987 to mid 1996s the condition was neutral except in the year 1988. In 1997s thermal comfort index was rising sharply to the pick value of warm condition threshold at 0600Z. The values decreased and indicated as neutral condition from mid 1998s and maintain this condition to 2010s despite of slight rising of value in 2007. At 1200Z the thermal comfort index was experienced within the range of warm condition from 1980s to 2010s.

Tanga station was experienced neutral condition from beginning of observing period 1980 to 2010s except in three periods of 1983s, mid 1994s to 95s, 2003, 2004 and 2010s. At 1200Z the warm condition was experienced from 1980s to 2010s

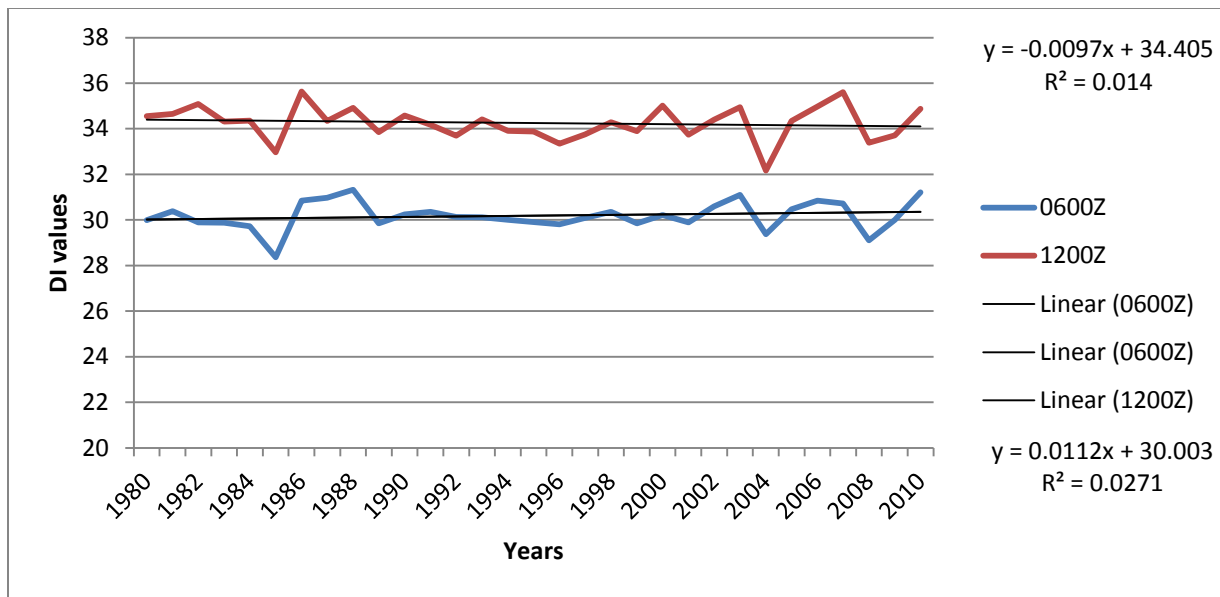


Figure 13: Thermal comfort Trend(Wind chill index) for the month of February over Dar es salaam.

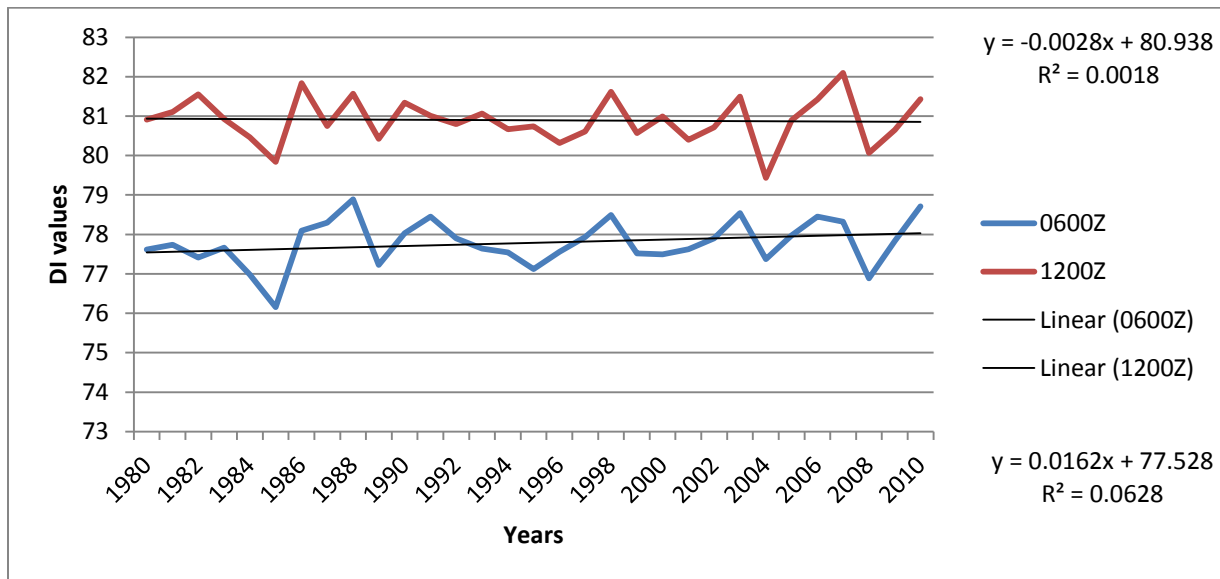


Figure 14: Thermal comfort Trend(Kawamura's Index) for the month of February over Dar es salaam.

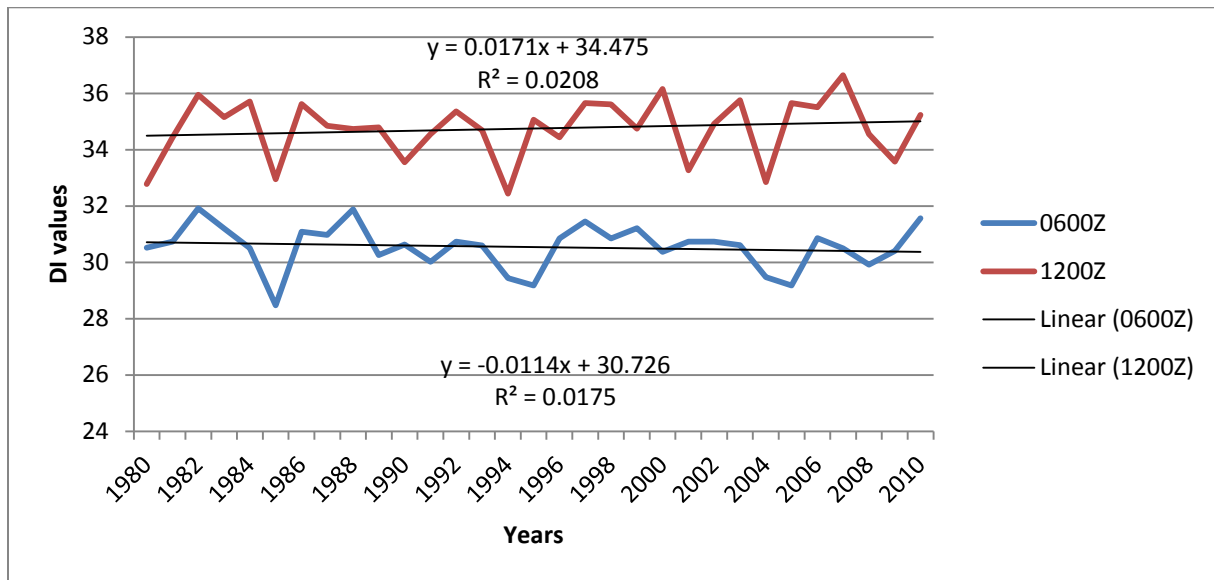


Figure 15: Thermal comfort Trend(Wind chill index) for the month of February over Zanzibar.

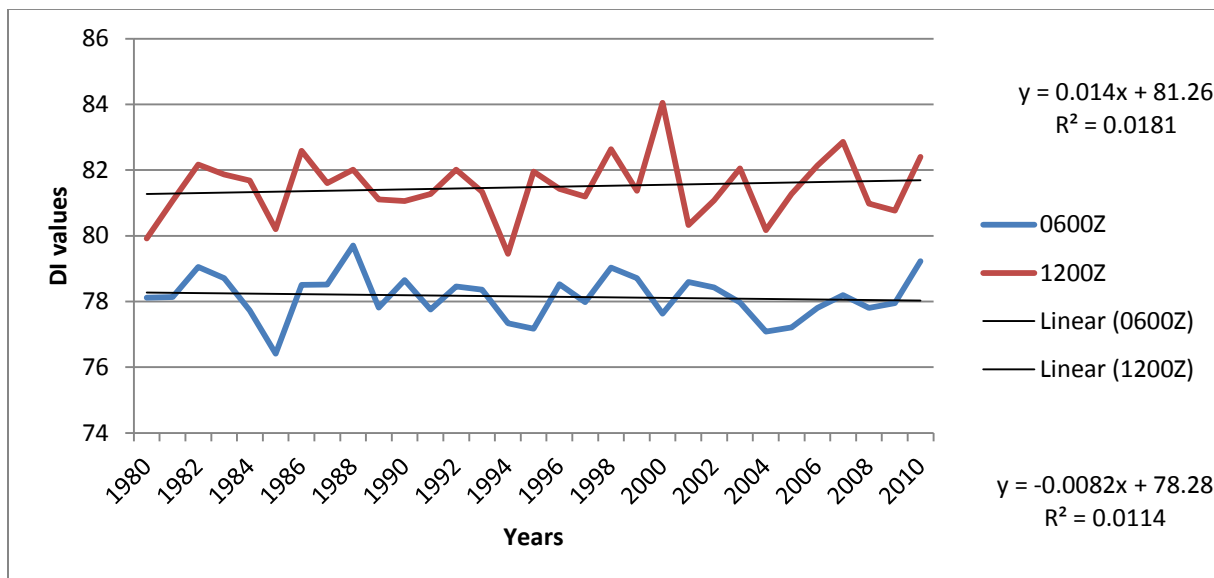


Figure 16: Thermal comfort Trend(Kawamura's Index) for the month of February over Zanzibar.

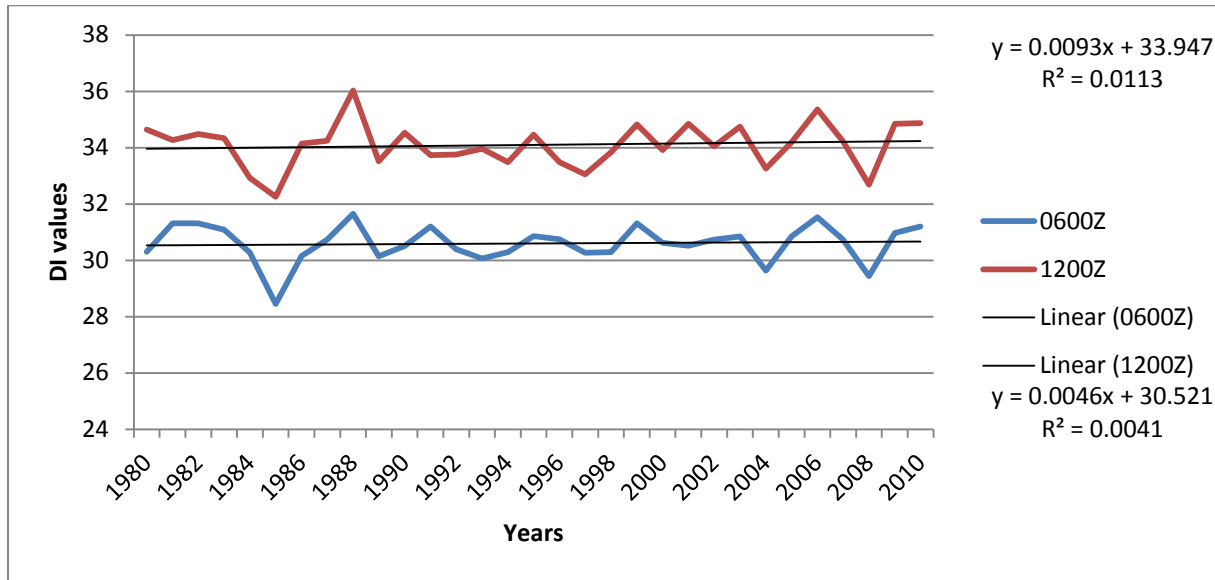


Figure 17: Thermal comfort Trend (Wind chill index) for the month of February over Tanga.

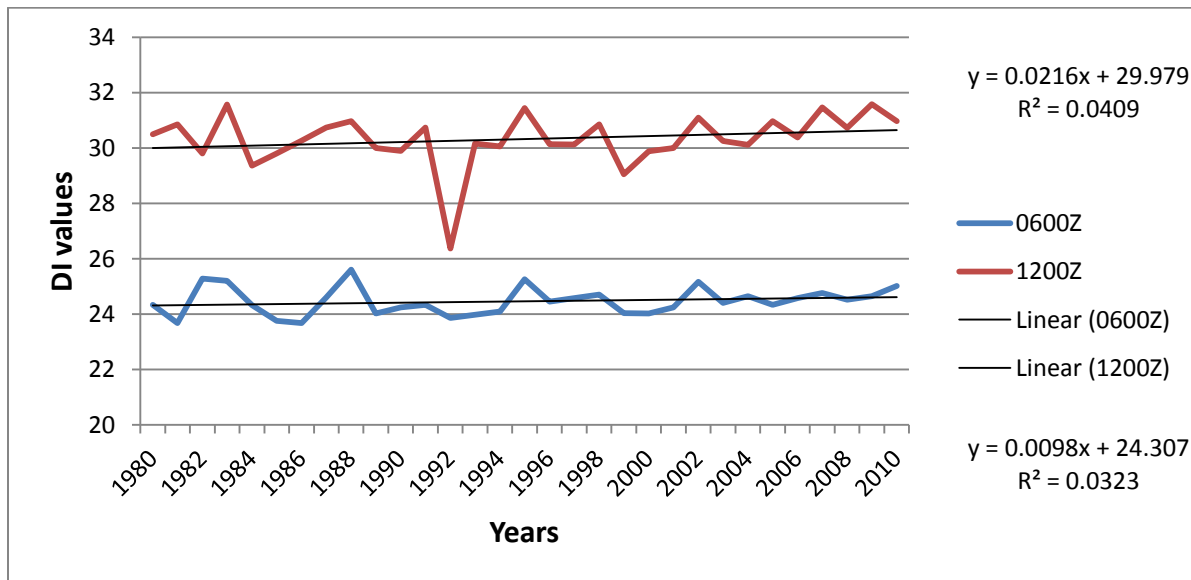


Figure 19: Thermal comfort Trend(Wind chill index) for the month of July over Dar es Salaam

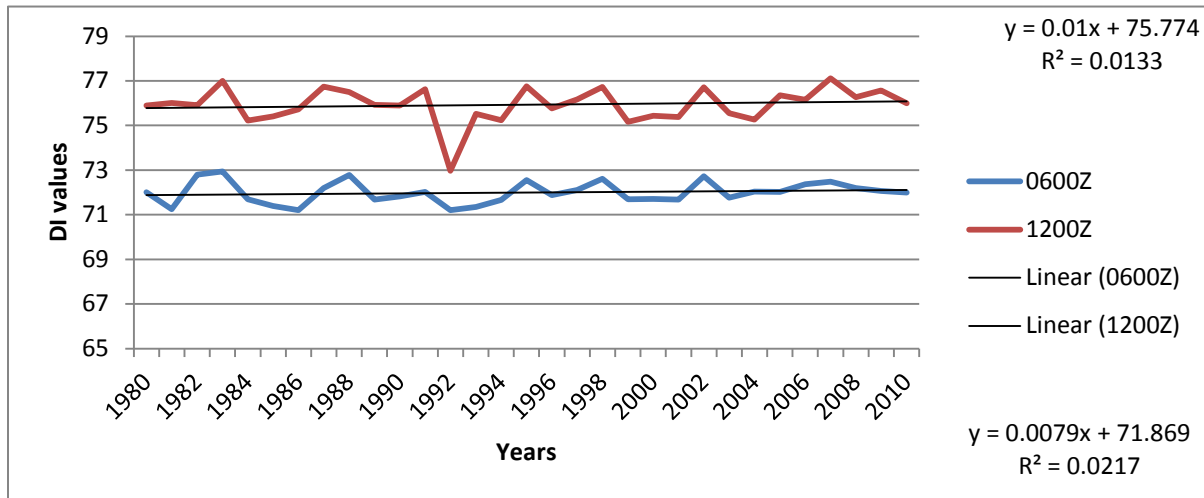


Figure 20: Thermal comfort Trend(Kawamura Index) for the month of July over Dar es Salaam

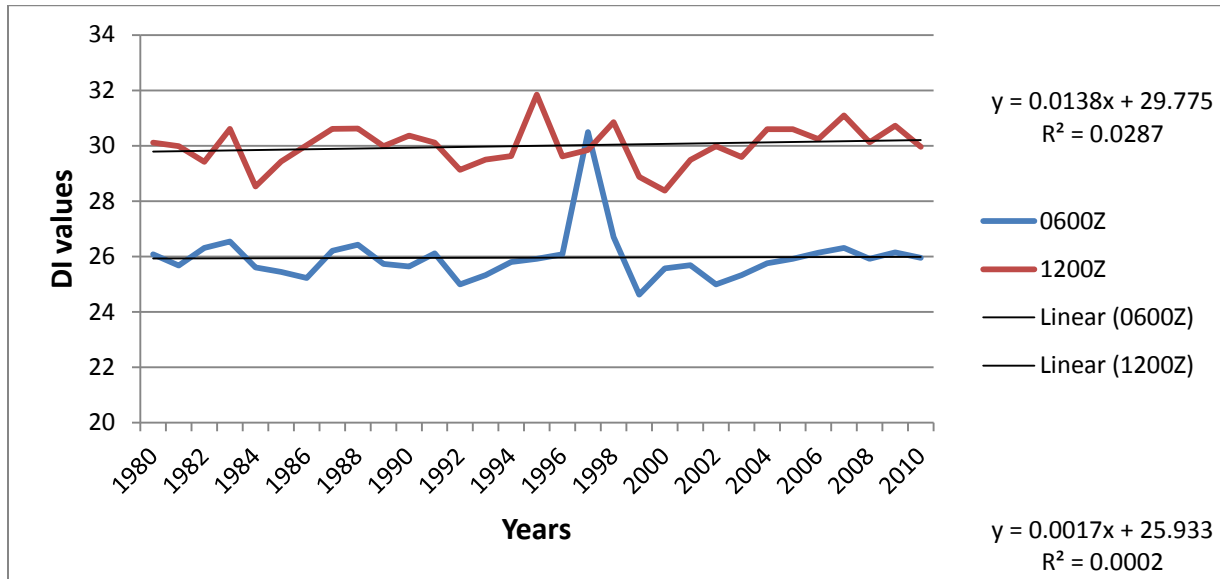


Figure 21: Thermal comfort Trend (Wind chill Index) for the month of July over Zanzibar

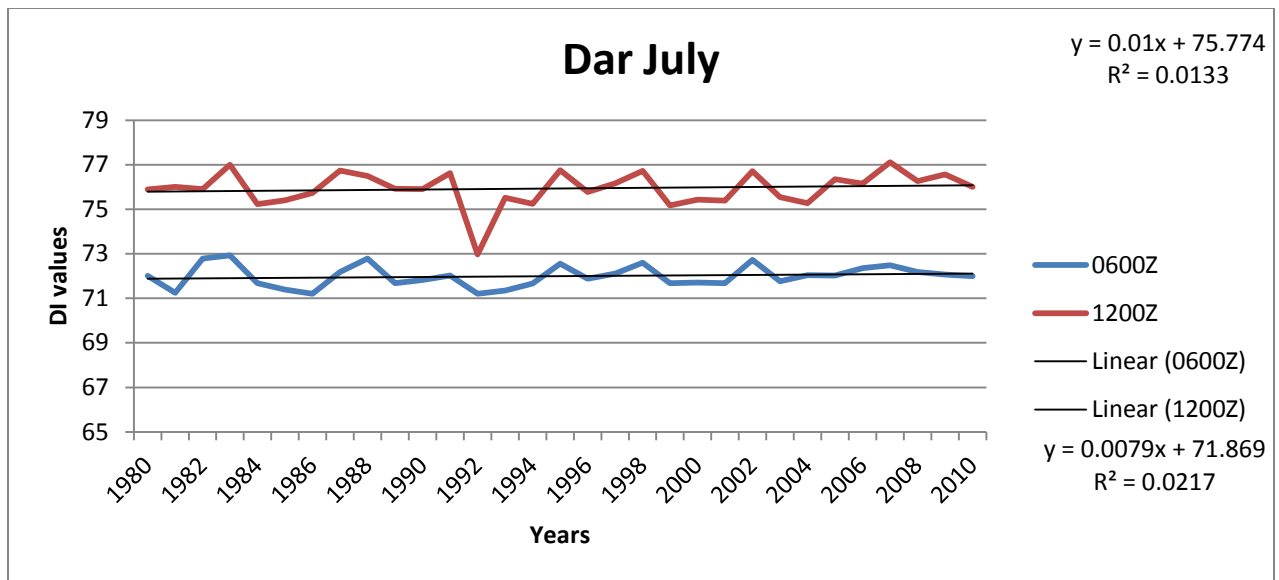


Figure 22: Thermal comfort Trend(Kawamura Index) for the month of July over Zanzibar.

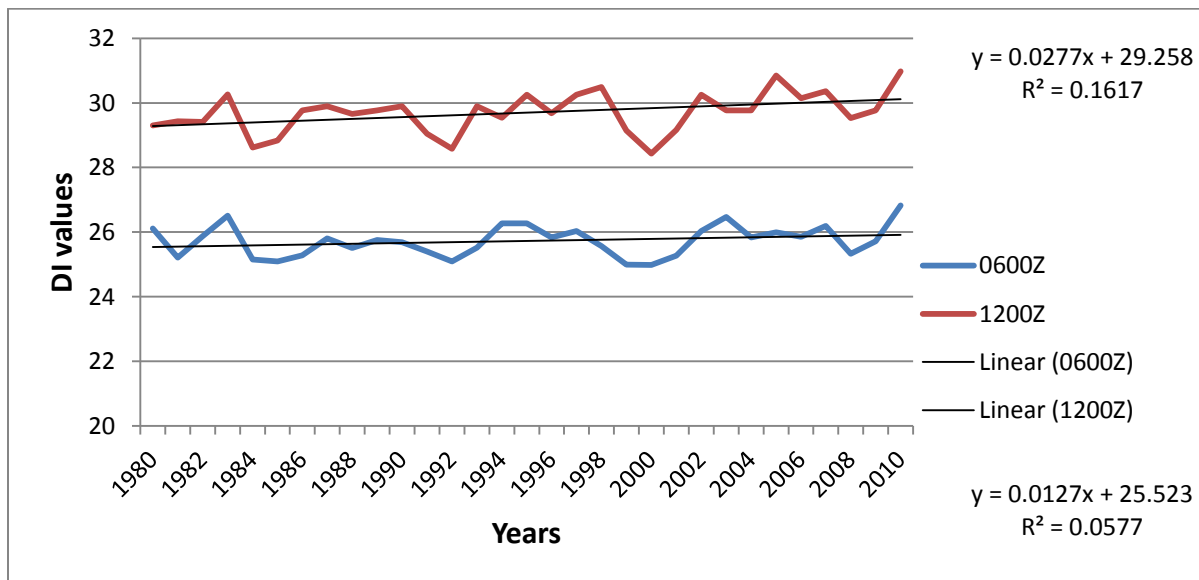


Figure 23: Thermal Comfort Trend (Wind chill Index) for the month of July over Tanga.

4.3.4 SPATIAL ANALYSIS

The spatial annual thermal comfort index variation for the month of July and February was analyzed over three stations which are Dar es Salaam, Zanzibar and Tanga. These are depicted in figure 24 to 31.

At 0600Z for the month of February the spatial thermal comfort variation indicates thermal comfort is higher over Tanga station followed by Zanzibar while the lowest indicated over Dar es Salaam. At 1200Z the highest level of thermal comfort index was indicated over Zanzibar followed by Dar es Salaam while the lowest indicated over Tanga.

The difference in the index values can be attributed to the different bioclimatic condition and topography of the three cities.

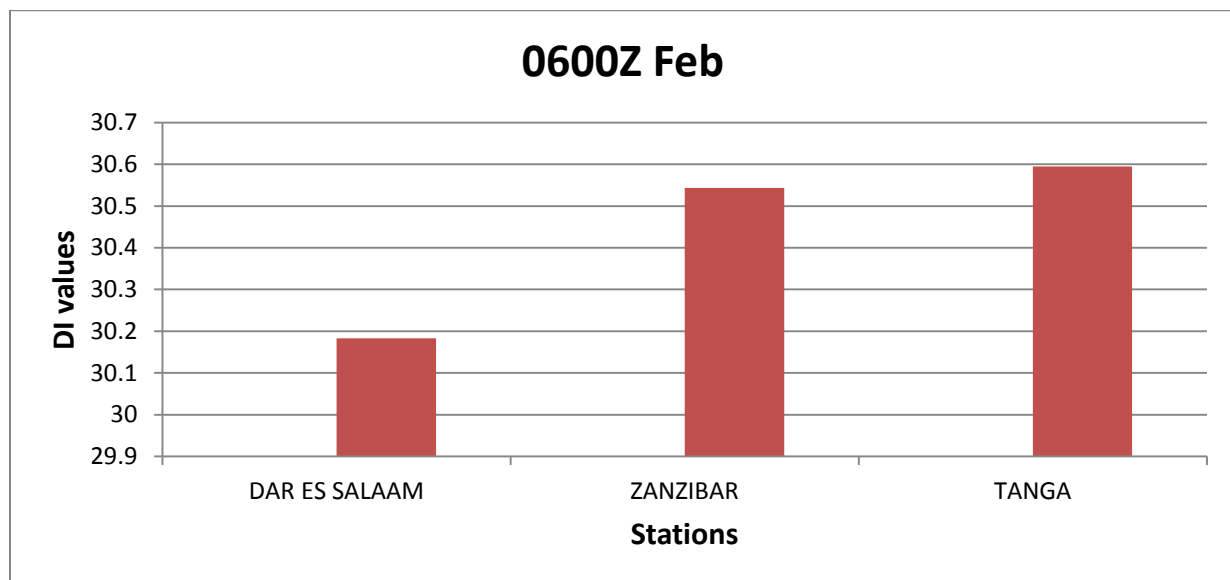


Figure 24: Spatial variation of thermal comfort index (Wind chill Index) for the month of February.

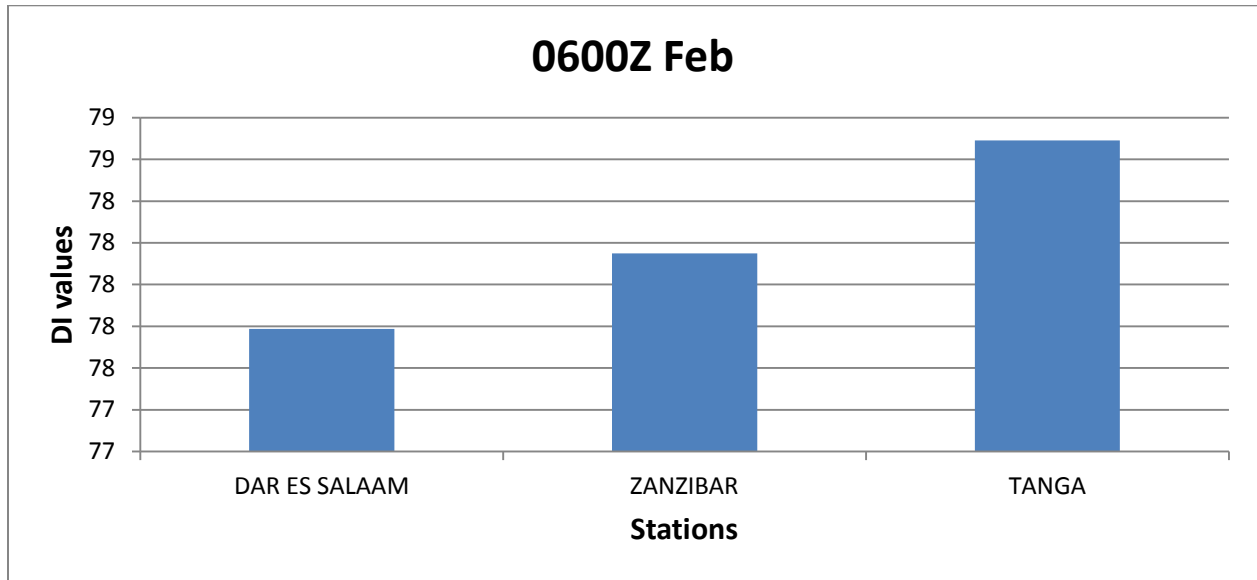


Figure 25: Spatial variation of thermal comfort index (Kawamura's discomfort Index) for the month of February.

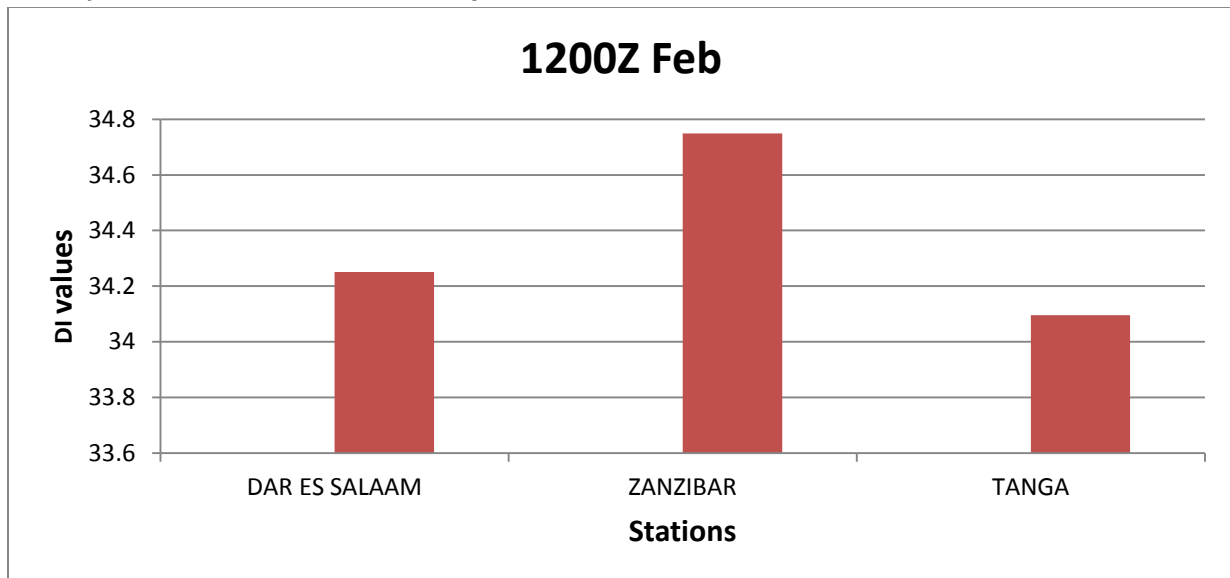


Figure 26: Spatial variation of thermal comfort index (Wind chill Index) for the month of February

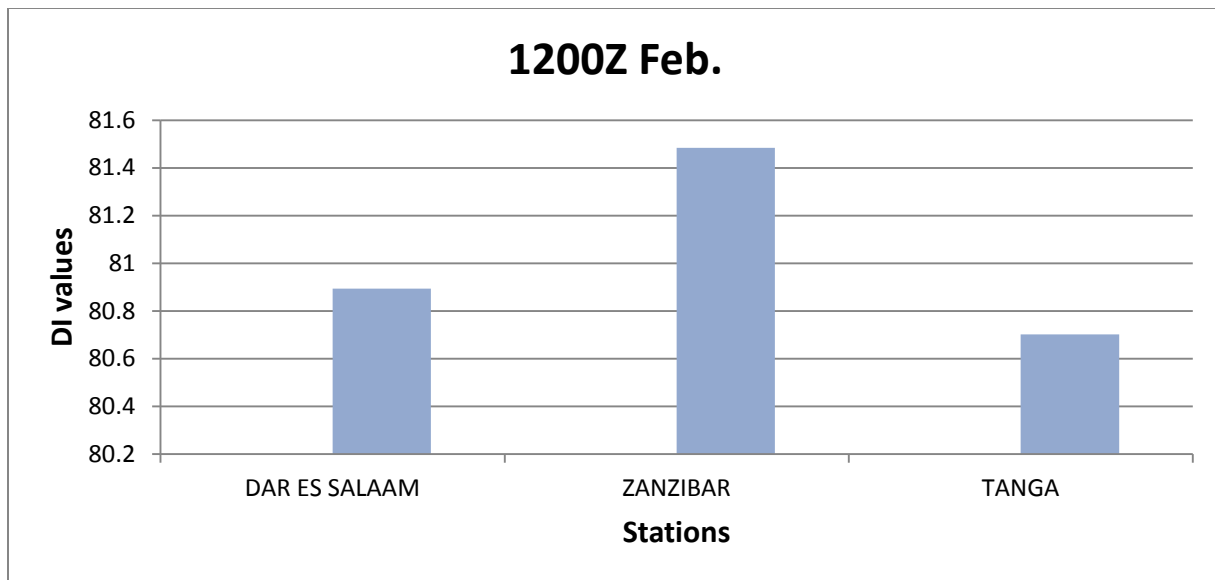


Figure 27: Spatial variation of thermal comfort index (Kawamura’s Discomfort Index) for the month of February.

Although thermal comfort Indices from both wind chill and Kawamura’s Discomfort index indicated the condition of comfortable but they differed from the level of comfort index between the stations.

At 0600Z for the month of July the spatial thermal comfort variation indicated thermal comfort index is highest over Zanzibar followed by Tanga while the lowest indicated over Dar es Salaam by using Wind chill Index while indicated that Tanga stations had the highest value followed by Zanzibar while the lowest indicated over Dar es Salaam.

At 1200Z the same case as at 0600Z where the different indices showed the different levels of thermal comfort index value at the same time. Using the Kawamura’s Discomfort index the highest level was indicated over Zanzibar followed by Tanga when the lowest was observed over Dar es Salaam while the highest value was indicated over Dar es Salaam followed by Zanzibar and lowest was Tanga. Despite the different between them, the overall condition was indicated the same which was uncomfortable condition.

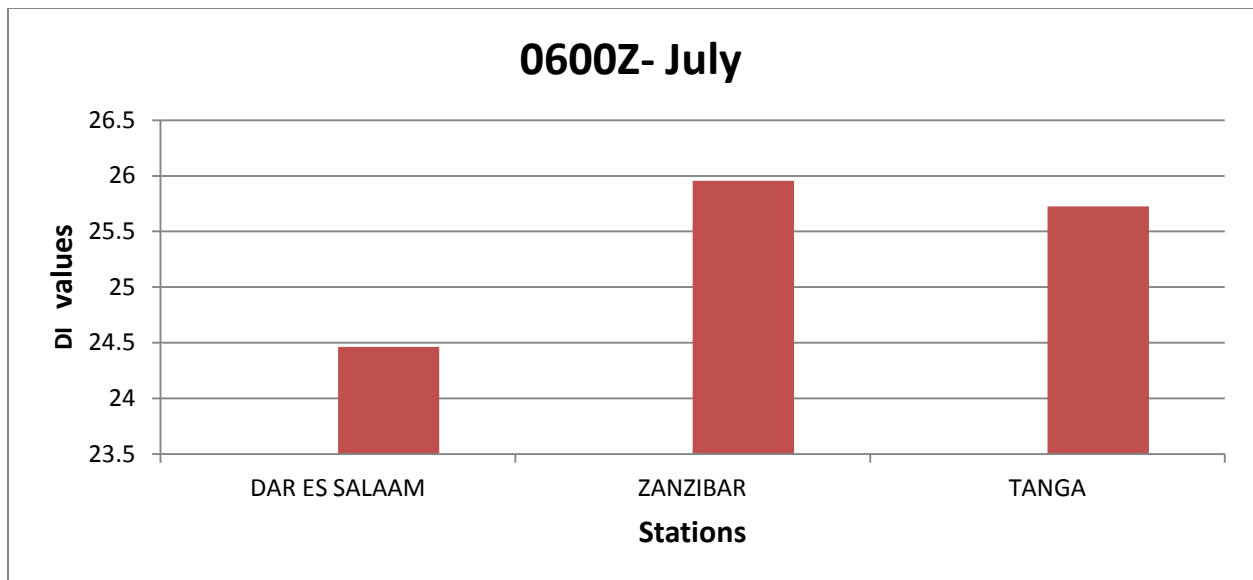


Figure 28: Spatial variation of thermal comfort index (Wind chill Index) for the month of July.

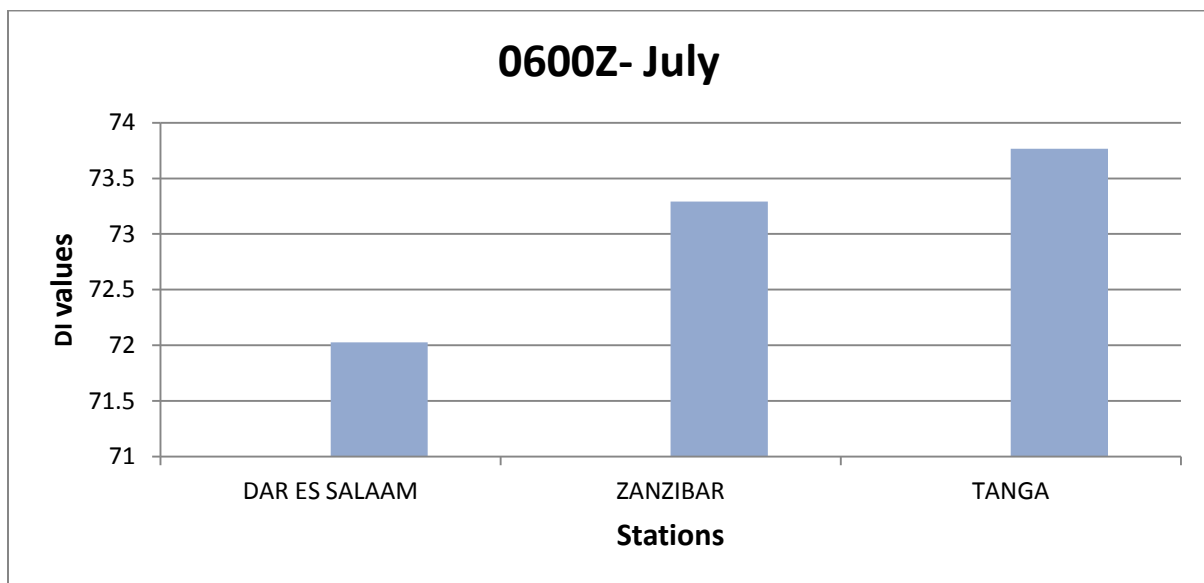


Figure 29: Spatial variation of thermal comfort index (Kawamura’s Discomfort Index) for the month of July.

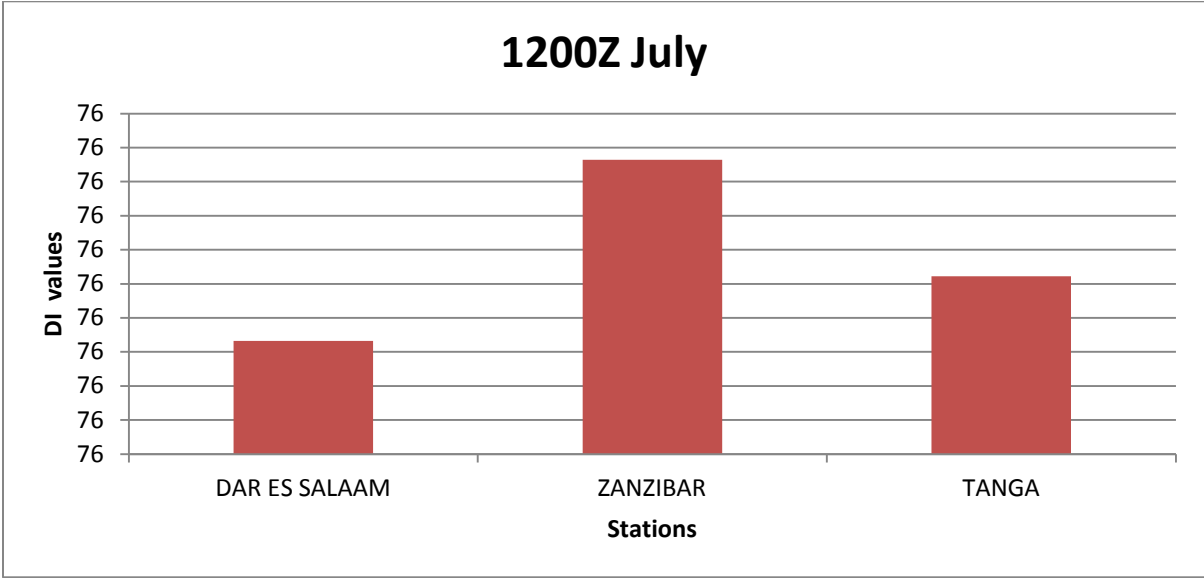


Figure 30: Spatial variation of thermal comfort index (Kawamura’s Discomfort Index) for the month of July.

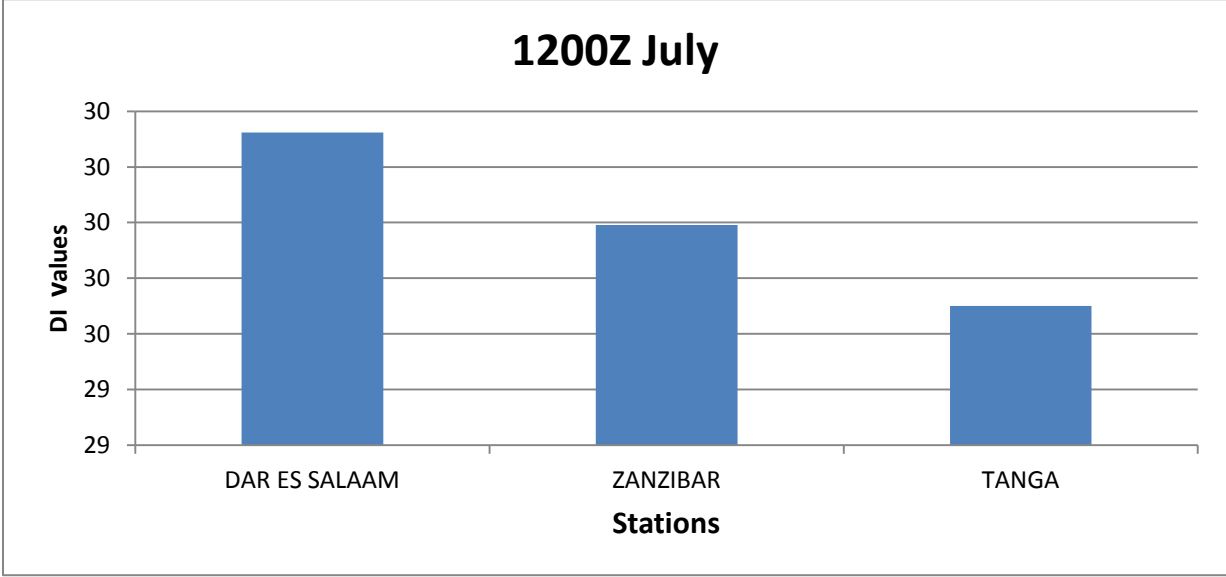


Figure 31: Spatial variation of thermal comfort index (Wind chill Index) for the month of July.

4.4.0 Relationship between Thermal Discomfort Index and Population.

The values of discomfort index were plotted (scatter plot) against population for the stations of Dar es Salaam, Zanzibar and Tanga and relationship observed as shown in the figures 32 to 37 below. 95% Confidence interval was used to test the signified of the correlation coefficient.

It shows that, weak positive relationship between thermal comfort index and population at morning (0600Z) and weak negative relationship at afternoon (1200Z). However, thermal comfort index showed no significant relationship indicated by the magnitude of t computed less than the t tabulated. . Therefore the growth of thermal discomfort index in three cites might be driven highly by the continuous increase of buildings, paved roads, buses as well as the decrease of cultivated land rather than population.

Table 8: Correlation between population and thermal comfort index.

	<i>Population DAR</i>	<i>t-test</i>	<i>Population ZNZ</i>	<i>t-test</i>	<i>Population TG</i>	<i>t-test</i>	<i>t-tab</i>
Dk06	0.24181	1.34200	0.23881	1.32400	0.25152	1.39900	2.045
Dk12	-0.00676	0.03640	-0.03643	0.19630	-0.02599	0.14000	2.045

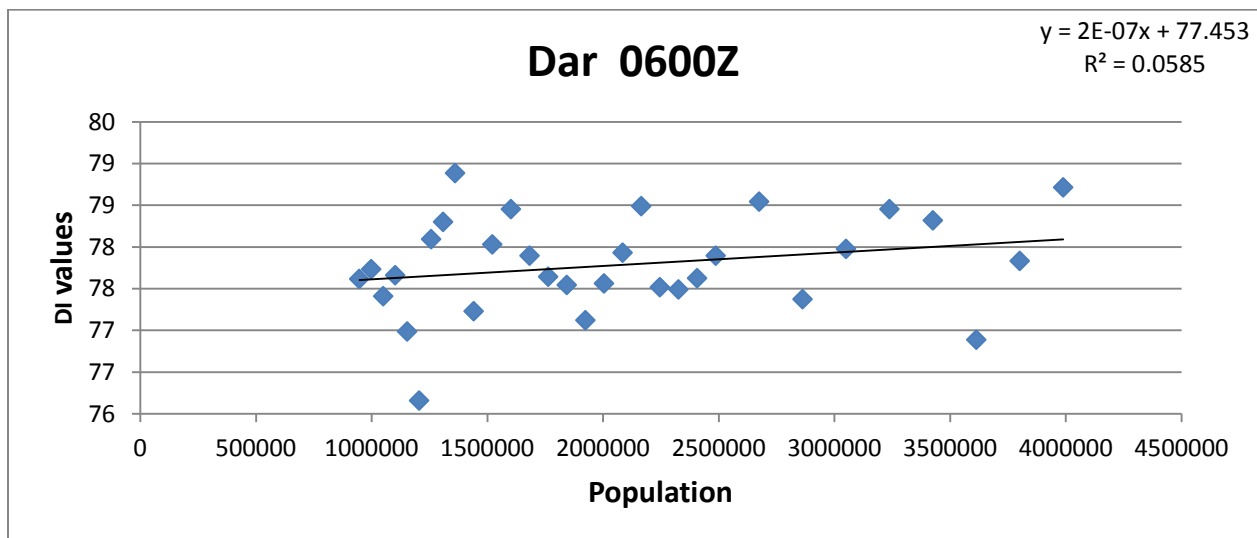


Figure 32: A plot of discomfort index against population over Dar es Salaam at 0600Z (1980-2010)

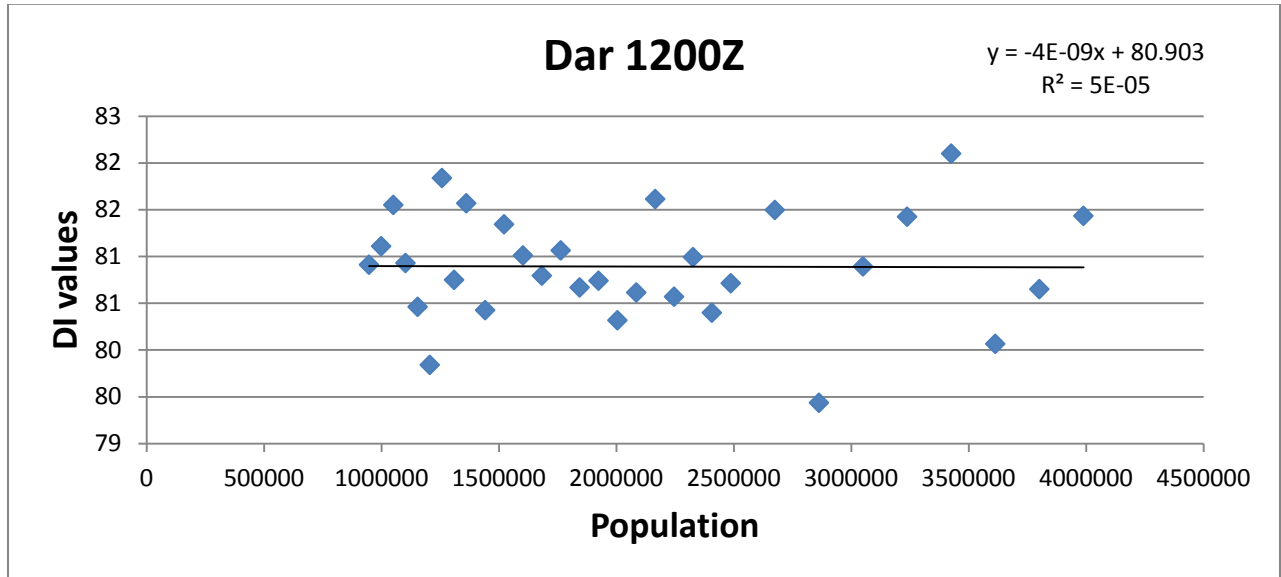


Figure 33: A plot of discomfort index against population over Dar es Salaam at 1200Z (1980-2010)

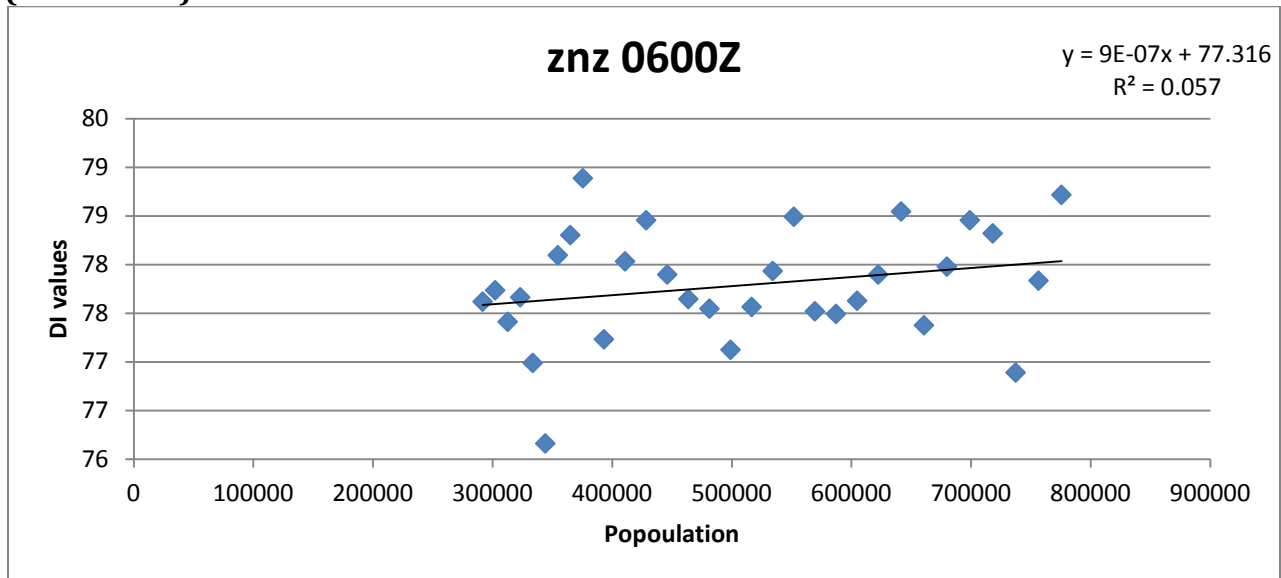


Figure 34: A plot of discomfort index against population over Zanzibar at 0600Z (1980-2010)

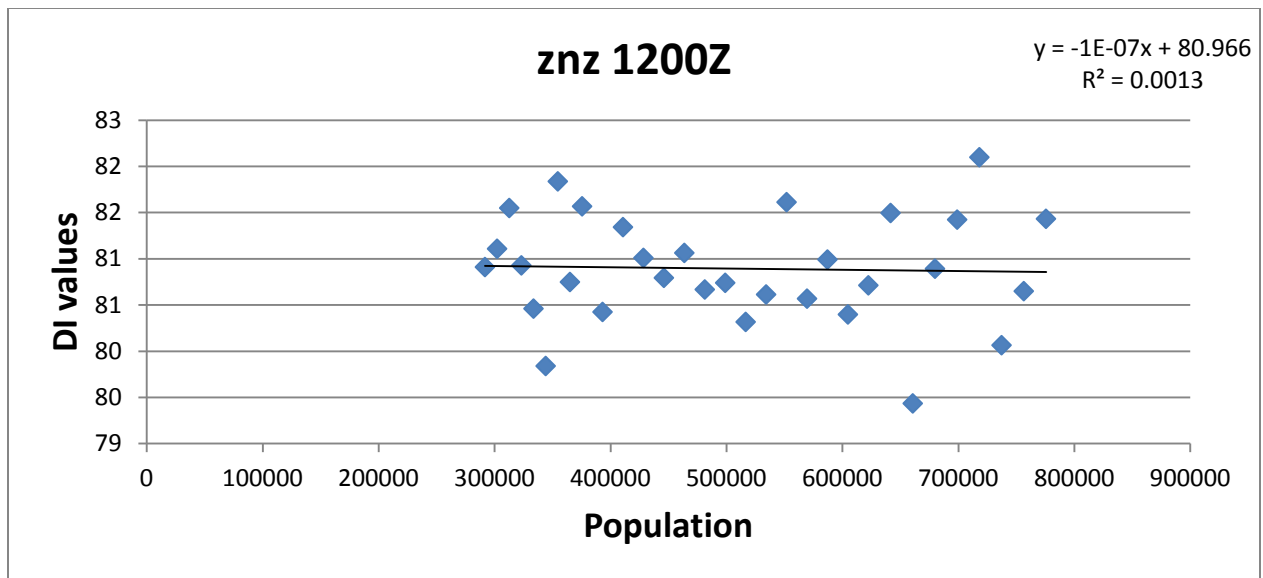


Figure 35: A plot of discomfort index against population over Zanzibar at 1200Z (1980-2010)

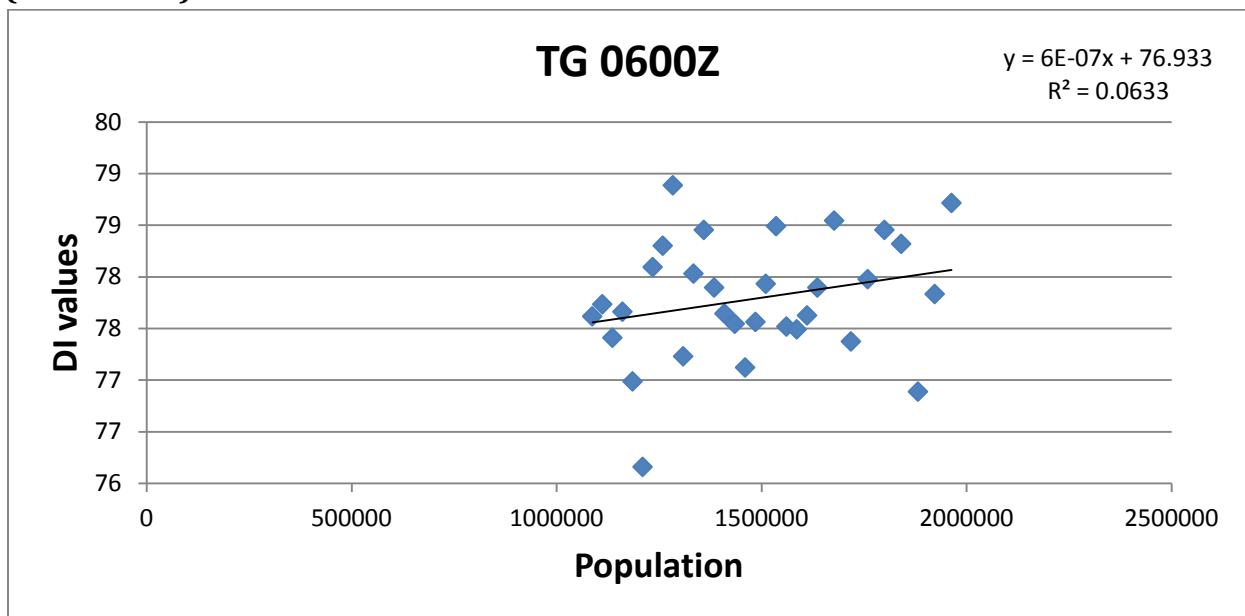


Figure 36: A plot of discomfort index against population over Tanga at 0600Z (1980-2010)

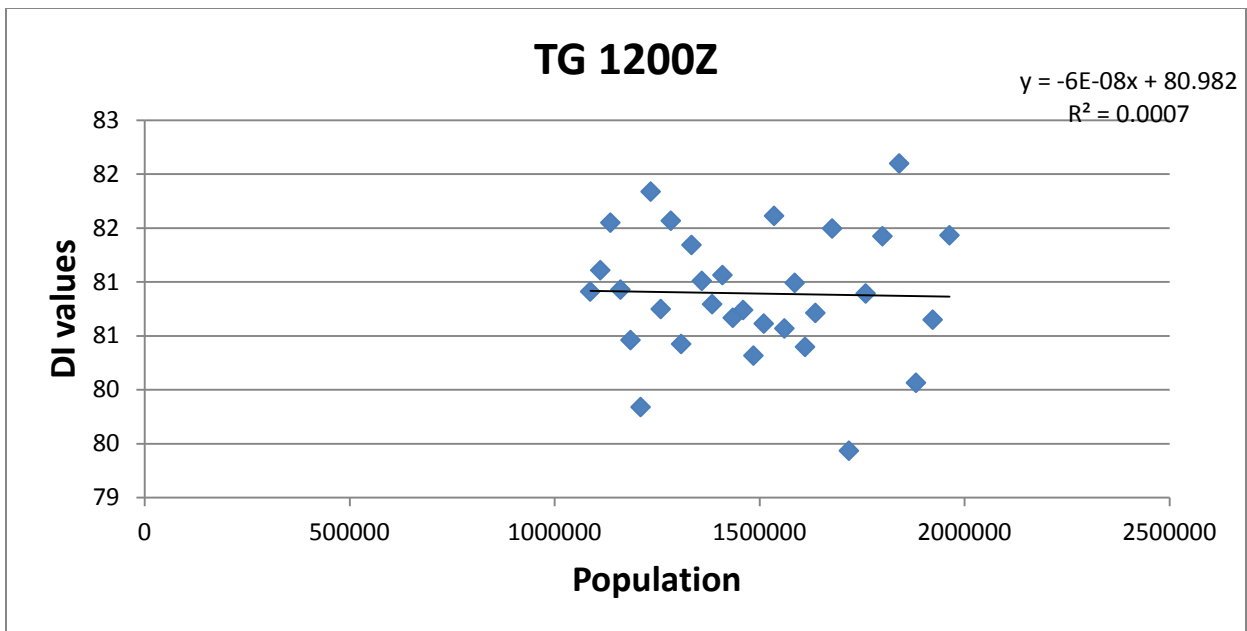


Figure 36: A plot of discomfort index against population over Tanga at 1200Z 1980-2010)

CHAPTER FIVE.

5.0 CONCLUSION

In the present study, two bioclimatic indices that are Kawamura's Discomfort Index [DIK] (KAWAMURA, 1965) which uses air temperature and dew point temperature and Wind chill Index which uses air temperature and wind speed (10m) in kilometer per hour were applied to determine thermal discomfort values. The strong positive linear relationship between these two indices was observed and their output defined the same condition. From this analysis the following conclusions can be outlined

The amplitude of the mean variation at afternoon (1200Z) was larger than in the morning (0600Z) at all three cities. It was found that people feel comfortable only during June, July and August (JJA) with discomfort index ranging from 74 to 81 for Kawamura's Index and from 24 to 35 for Wind chill Index.

The results from the spatial analysis show that the amplitude of mean DI values at 0600Z is larger over Tanga than Zanzibar and Dar es Salaam. While at 1200Z is larger over Zanzibar then Dar es Salaam and Tanga. This is because of different cities characteristics such as sparse urban green, buildings as well as cars and geographical location.

Finally, study shows that no significant relationship in population data and thermal comfort index. Therefore, the growth of thermal DI in three cities should be driven highly by the continuous increase of buildings, paved roads, buses as well as the decrease of cultivated land rather than population. Hence this study may be applicable in Tourist sector, viewpoint of city planning, construction and environmental protection.

5.1 RECOMMENDATION

The present study on the assessment of effect of urbanization on thermal comfort index shows that there is a weak negative and positive linear relationship between the population and thermal comfort index. However, the result was not significant. It is therefore strongly recommended that more studies of effect of urbanization should be done.

In this study, monthly mean dry bulb temperature, dew point temperature and wind speed were used to determine the thermal comfort index. Hence further studies based on the daily data should be done.

In the present study, assessment was done over some parts of the coast of Tanzania. More studies over other parts of Tanzania are necessary.

Results from the present study indicated that, people suffer from hot stress throughout the year except during month of June, July and August (JJA). It is therefore strongly recommended that:-

- ✓ Need for Urban designers to take the thermal comfort index into consideration and people advice to dress appropriate.
- ✓ Various activities need to be synchronized with the diurnal variation of thermal index.
- ✓ Social economic activities be planned based seasonal pattern of thermal index to optimal enjoyment and benefit.
- ✓ The information on weather and thermal comfort be available to the tourists and other visitors so as to plan appropriately.

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APPENDIX

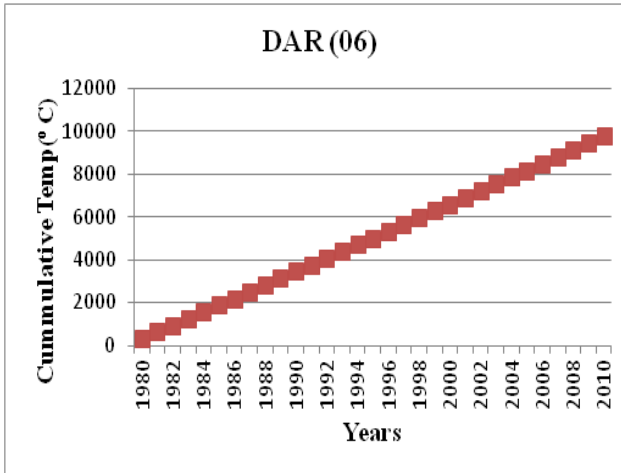


Fig. 1: Dar es Salaam Single mass curve for 0600Z dry bulb temperature.(1980-2010)

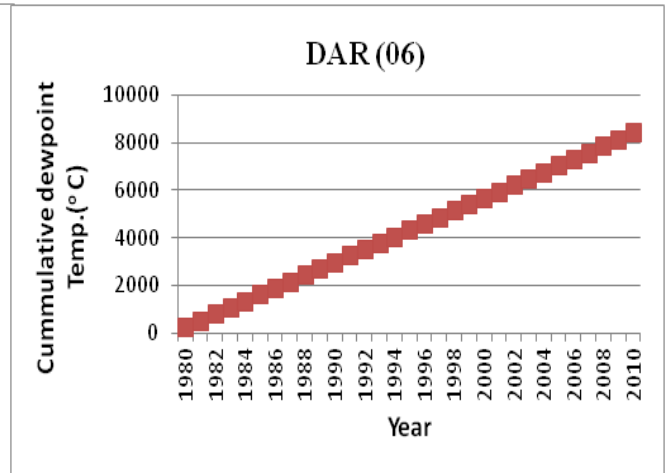


Fig. 2: Dar es salaam Single mass curve for 0600Z dew point temperature.(1980-2010)

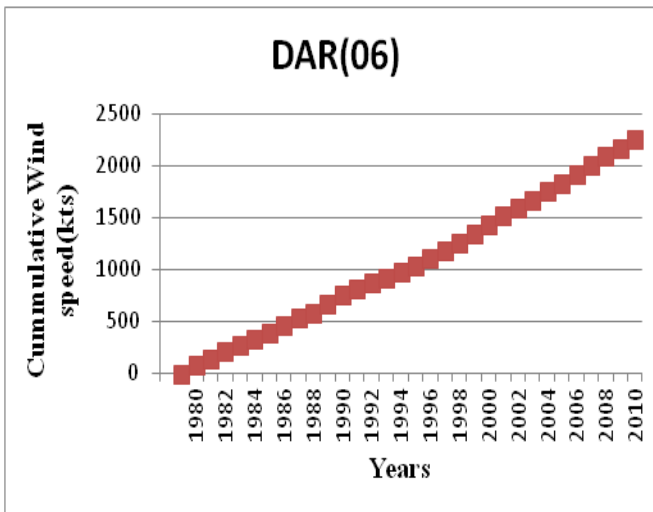


Fig. 3: Dar es salaam Single mass curve for 0600Z wind speed.(1980-2010)

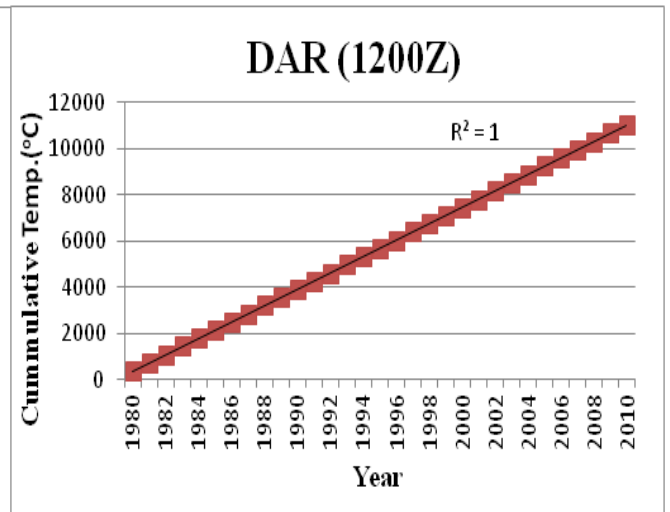


Fig. 4: Dar es Salaam Single mass curve for 1200Z dry bulb temperature.(1980-2010)

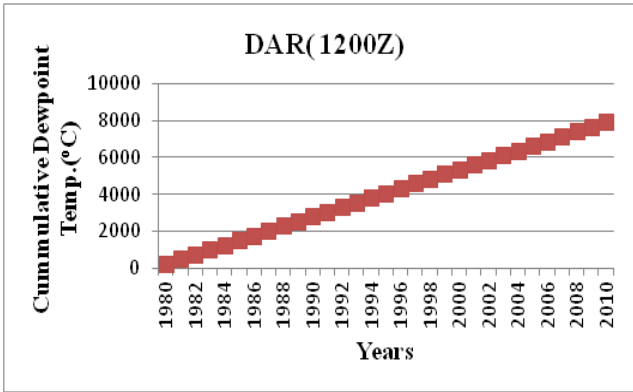


Fig. 6: Dar es Salaam Single mass curve for 1200Z wind speed.(1980-2010)

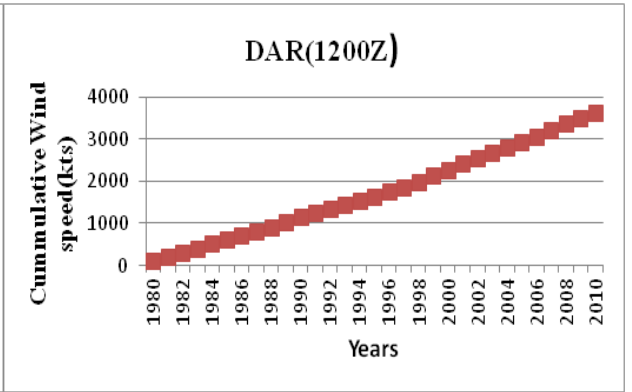


Fig. 7: Zanzibar Single mass curve for 0600Z dry bulb temperature.(1980-2010)

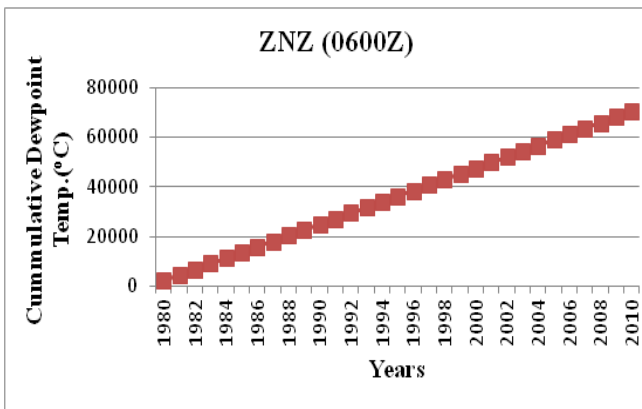


Fig. 8: Zanzibar Single mass curve for 0600Z dry dew point temperature.(1980-2010)

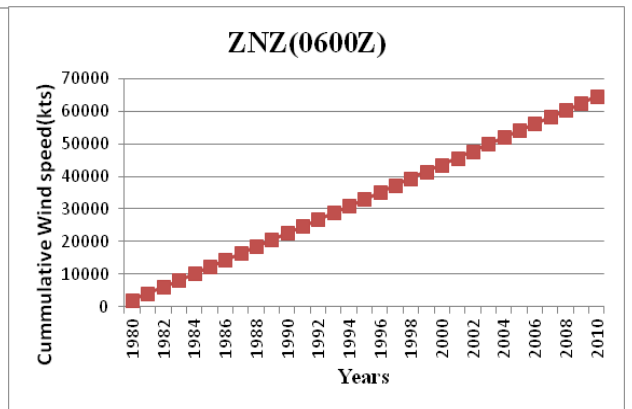


Fig. 9: Zanzibar Single mass curve for 0600Z wind speed.(1980-2010)