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THERMAL CONDITION OVER AN INDUSTRIAL AREA IN SOUTHWESTERN NIGERIA

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ABSTRACT

The study examined selected thermal comfort indices over Oluyole Industrial region in Ibadan, Oyo State, Nigeria. Specific objectives were to describe the thermal condition of the selected industrial region and examine the relationship between the unitary and integrative indices over the area. Temperature and relative humidity data were collected using a whirling psychrometer. Dew point temperature and heat index or humidex temperature (temperature felt by the skin rather than the actual temperature due to the humidity level) were calculated by using Fanger's formula in an NOAA's weather calculator. The study showed that average temperature was 35.2^{o}C while average relative humidity was 51%, and the dewpoint temperature and heat index were 22.8^{o}C and 41.9^{o}C, respectively. Dewpoint temperature was shown to relate stronger with heat index, and lesser with either air temperature or relative humidity. The study concluded that residents in the industrial region are likely to feel warmer than the ambient air temperature, and this is associated with the effect of the industrial activities in the area. The study recommends greening of the industrial area for effective reduction of the heat stress in industrial region. It also suggests policy for adequate monitoring of industrial region for significant temperature change.

Keywords: Dewpoint temperature, Heat Index, Industrial area, Thermal indices

1. INTRODUCTION

Industrialization is considered as the cornerstone of development strategies, because the industries often contribute significantly to economic growth and human welfare. Industrialisation is an important yardstick for placing countries in the League of Nations, and also an index of its political stature because they create finished products,

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provides employment which reduces poverty, and generate income for the government through taxes (Chenery et al, 1986; Seuring, 2004). Location of industries has also been associated with increased amount of gaseous pollutants, as well as generation of refuse and wastewaters, which are often discharged into the adjacent environment where they cause pollution (Mani and Wheeler, 1998; RaashouNielsen et al, 2013). Industrial areas are also associated with urbanisation, population congestion and health related problems. Industrial centres are also characterised by altered local or micro climate because they create temperature that is higher than the surroundings, and thereby giving rise to the creation of an urban heat island (UHI).

The UHI is an area with higher surface and near-surface air temperature than its surrounding areas (Voogt, 2002; Rizwan et al, 2008). The UHI can be generated with elevated heat that is associated with energy from industries and automobiles. The UHI effect exists due to the greater heat retention of buildings and man-made surfaces such as concrete and asphalt, ubiquitous in cities, compared to the lesser heat retention and cooling properties of vegetation, which is more abundant in the countryside (Adebayo, 1990; Adebayo, 1991; Kim and Baik, 2005; Alcamo et al., 2007; Lee et al, 2017).

Whereas the many studies have investigated the contributions of industrialisation and urbanisation at the macro and meso-scales (including national, regional and city based studies), whose results are more generalised, only few have targeted a specific layout in a city within the micro-scale window, and this is the focus of this study. Main objective is to examine the diurnal variations in surface air temperature, relative humidity dew point temperature over Oluyole industrial estate. The estate in Ibadan is a typical industrial layout in the southwest Nigeria, consisting of cottage to medium scale food and beverage industries, including the Yale Foods Nigerian Limited, Caps Feed Nigerian Limited, and 7up Bottling Company, among others.

The present study is aimed at examining thermal characteristics of a typical industrial area in the southwest Nigeria with a view to determining the relationship between selected unitary and integrative indices in the region. Specific objectives are to describe the thermal condition of the selected industrial region and examine the relationship between the unitary and integrative indices over the area.

2. STUDY AREA

The selected industrial estate is situated in Ibadan, the largest city in the subSaharan Africa, and the capital of Oyo State (7.4^{o} N, 3.9^{o} E) (Figure 1).

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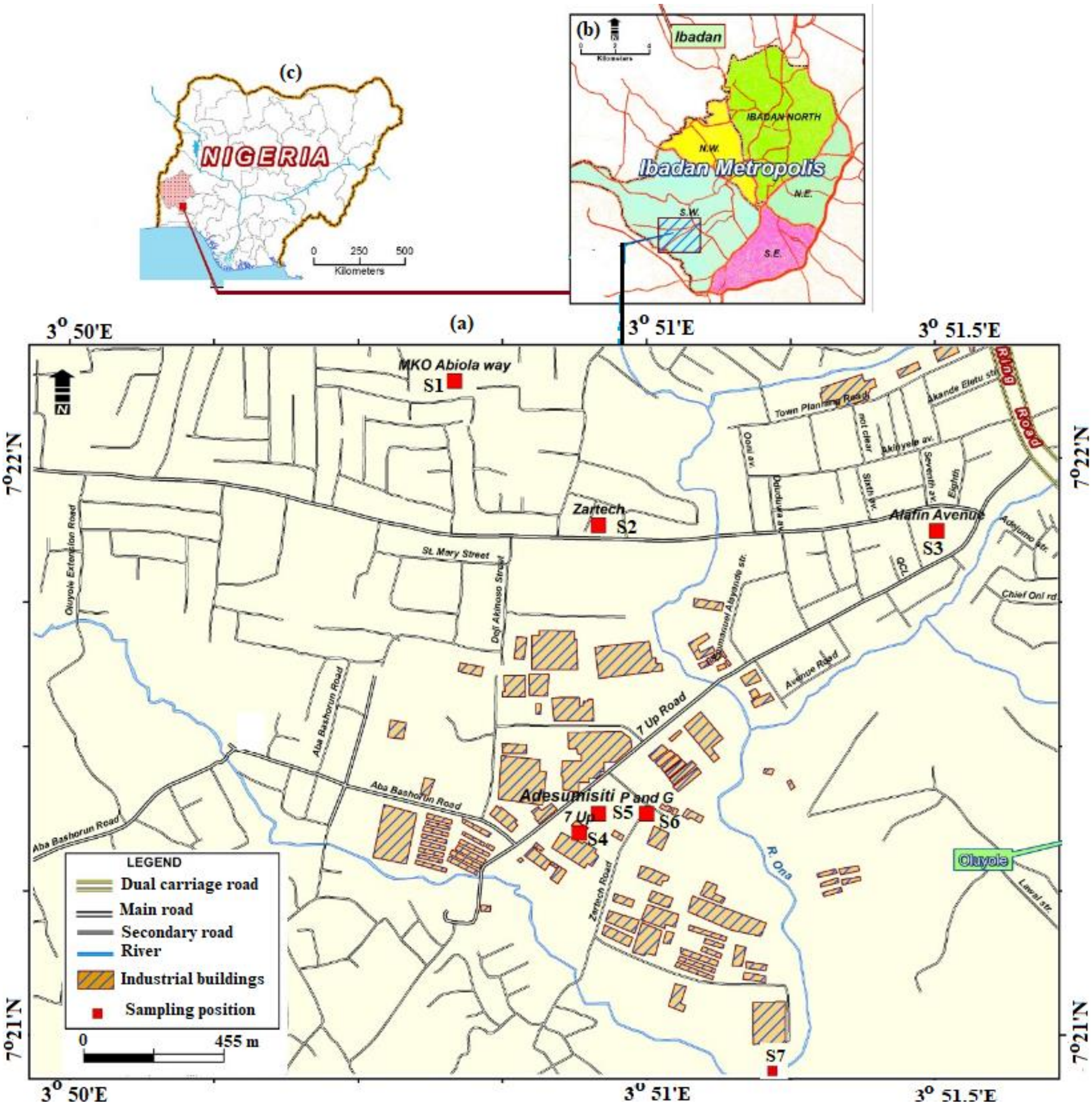

Figure 1. Map showing Oluyole Industrial Estate (a) in Ibadan (b), southwest Nigeria (c) and locations where measurements were taken for this study.

The study area's total area is 3,080 km^2 (Abatan et al, 2018). The population according to 2006 census was 1.3 million, and is projected to be about 2 million as at 2015, at an annual projection rate of 3.2%. The industrial estate is situated within Ibadan South West Local Government Area, and it is about 133,500 sq. km. The industrial estate has a good road network, many educational institutes, religion centres, commercial and service – rendering centres (including filling stations, supermarket, and event centres). Ibadan accounted for about 6% of the nation's industrial activity in the 1970s, and

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industrial growths have since then become an important factor of rapid urbanisation in the recent years (Filani et al, 1994; Ajayi, 2007).

The climate of Ibadan is influenced by the tropical maritime air mass (mT), Tropical continental air mass (cT), and equatorial easterlies (Abatan et al, 2018). The mT originated from the southern high-pressure belt located off the Namibian coast and passes over the Atlantic Ocean and thus its moist, while the cT originates from the high-pressure belt of the north of the tropic of cancer, and it is dry (Iloeje, 2001; Eludoyin et al, 2014;). The two air masses meet intertropical discontinuity (ITD). The equatorial easterlies are rather erratic cool air mass which comes from the east and flow in the upper atmosphere of the intertropical discontinuity. The air masses drive down occasionally to actively undercut the mT and cT air mass and give rise to line squall or dust devils (Iloeje, 1972). Raining season in Ibadan runs from March through October, while November to February forms the city's dry season, this time Ibadan experiences the typical West African harmattan that originates from the Sahara, the city is under the influence of moist maritime south- west monsoon wind which blows inland from the Atlantic Ocean (Adebayo, 1991). The mean total annual rainfall for Ibadan is 1420.06 mm, falling in approximately 109 days.

3. METHODS

Air temperature and relative humidity readings were obtained at seven systematically selected locations (S1- S3 and S7, being outside the core industrial area, and S4-S6 are in the core industrial region) around the Oluyole Industrial Estate in Ibadan, Oyo State, Nigeria, within the study area using a sling whirling psychrometer. The readings were taken in the morning (0600 – 0900 Nigerian local standard time (NLST)), afternoon (1100 – 1400 NLST) and evening (1600 – 1800 NLST). To take readings, the instrument was whirled for a minimum of five minutes and watched at intervals until at least two consecutive readings were equal. The difference between the dry bulb (air temperature) and the wet bulb readings was checked under appropriate columns in the hygrometric tables to determine the equivalent relative humidity. Readings were made bearing in mind all the precautionary measures in the instrument manual to minimize possible errors. Data obtained from the readings were subjected to statistical analysis by calculating the mean for both temperature and relative humidity. Dew point temperature and heat index or humidex temperature (temperature felt by the skin rather than the actual temperature due to the humidity level) were calculated by using Fanger’s formula in an NOAA’s weather calculator (www.wpc.ncep.noaa.gov). Analysis of temperature and relative humidity data observations were performed using geostatistical procedures.

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4. RESULTS AND DISCUSSION

4.1. General pattern of heat variables in the area

The descriptive statistics of the investigated variables (air temperature, humidity, dewpoint temperature and heat index are presented in Table 1. Average temperature was 35.2°C and relative humidity was 51%. Dewpoint temperature and heat index were 22.8°C and 41.9°C, respectively, suggesting that greater heat was felt (on the skin) than the air temperature due to the low humidity. The variables exhibited low variability (coefficient of variation = 6 – 27.6%), which indicates diurnal variation. The median values were 34.5°C, 45.4%, 23.5°C and 42°C for air temperature, relative humidity, dewpoint temperature and heat index, respectively. Relative humidity exhibited more percentage variation (27.6%) than air temperature and dewpoint temperature.

Table 1. Description of the air temperature, relative humidity and dewpoint temperature over the study area

Sampling locations	Air temperature (°C)	Relative Humidity (%)	Dewpoint temperature (°C)	Heat index (°C)
S1	36.4 (29.2 – 38.3)	54 (41 – 65)	18.2 (15.0 – 28.2)	44(41 – 47)
S2	37.5 (27.1 – 39.2)	53 (38 – 71)	20.1 (17.9 – 28.5)	45.3 (39 – 52)
S3	35.4 (22.0 – 38.7)	44 (28 – 52)	24.2 (18.1 – 28.4)	37.7 (32 – 43)
S4	37.3 (29.0 – 40.0)	52 (48 – 71)	27.7 (25.5 – 28.2)	42.3 (36 – 49)
S5	36.3 (30.1 – 40.0)	46 (34 – 63)	25.5 (23.1 - 28.5)	37.7 (36 – 40)
S6	37.4 (36.1 – 37.5)	49 (38 – 56)	27.2 (24.0 – 28.5)	44.3 (37 – 49)
S7	34.4 (28.3 – 36.3)	50 (42 – 66)	22.8 (16.3 – 26.8)	42 (38 – 45)
Overall Mean ±SD (Min-Max)	35.2±2.2 (32.4 – 40.0)	51.0±14.1 (31 – 71)	22.8±4.1 (15.0 – 28.5)	41.9±5.2 (32 – 52)
Coefficient of variation (%)	6.3	27.6	17.9	12.4

The low values of coefficient of variation in heat temperature are in line with existing reports of small range in temperature in the tropics (Nieuwolt, 1977; Ogbonna and Harris, 2008). Heat index indicated that human skins in the region experienced more heat (were warmer) than the average ambient air temperature in the area. The spatio-temporal distribution of the selected indices also indicate variations in the locations of heat islands (locations with values of temperature that are greater than that

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of the surroundings). Figure 3a and b are samples of the spatial distribution for temperature and dew point temperature, respectively.

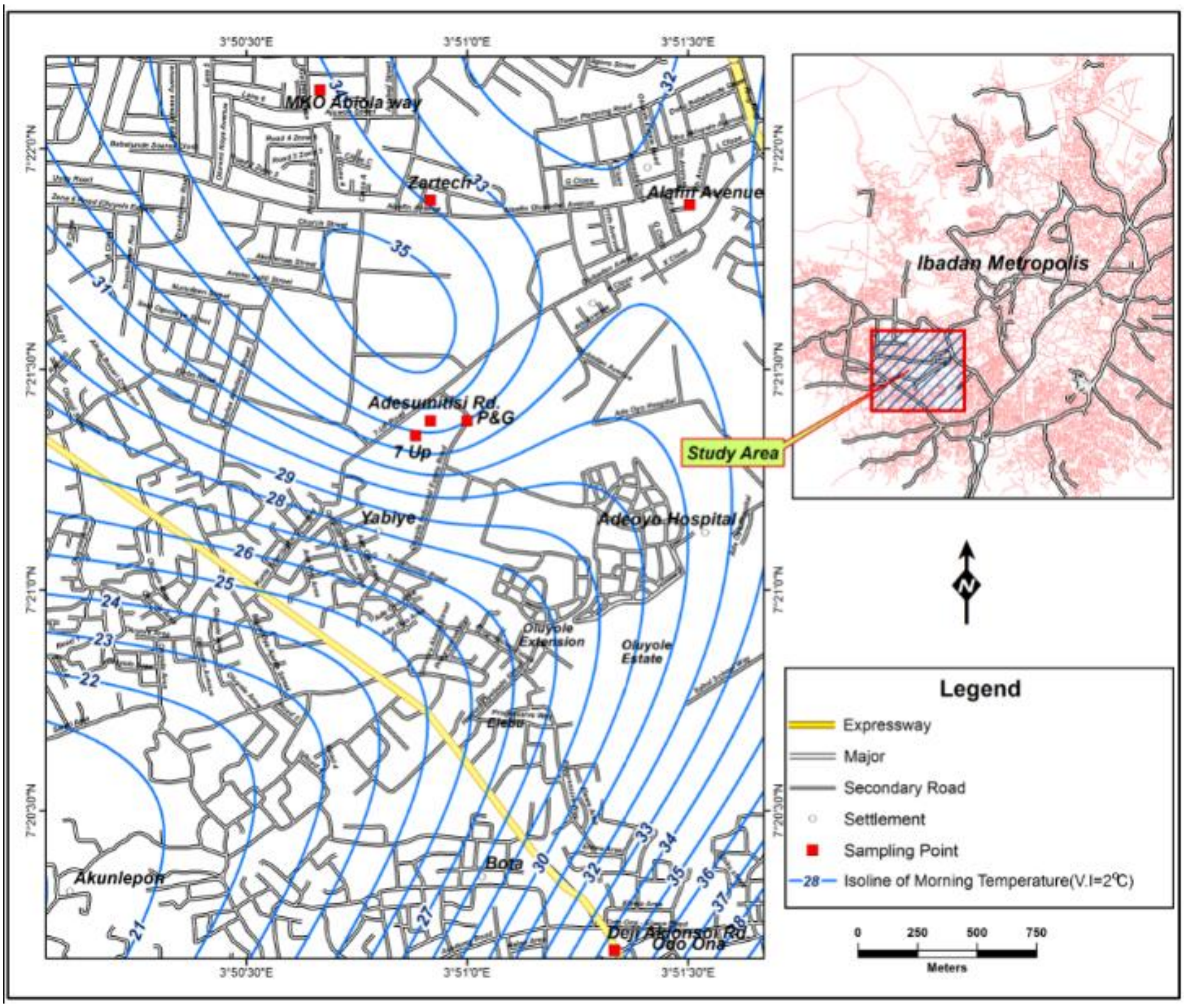

Figure 3a. Spatial variations in air temperature at morning time (06 – 10 NLST) over Oluyole Estate in Ibadan, Oyo State

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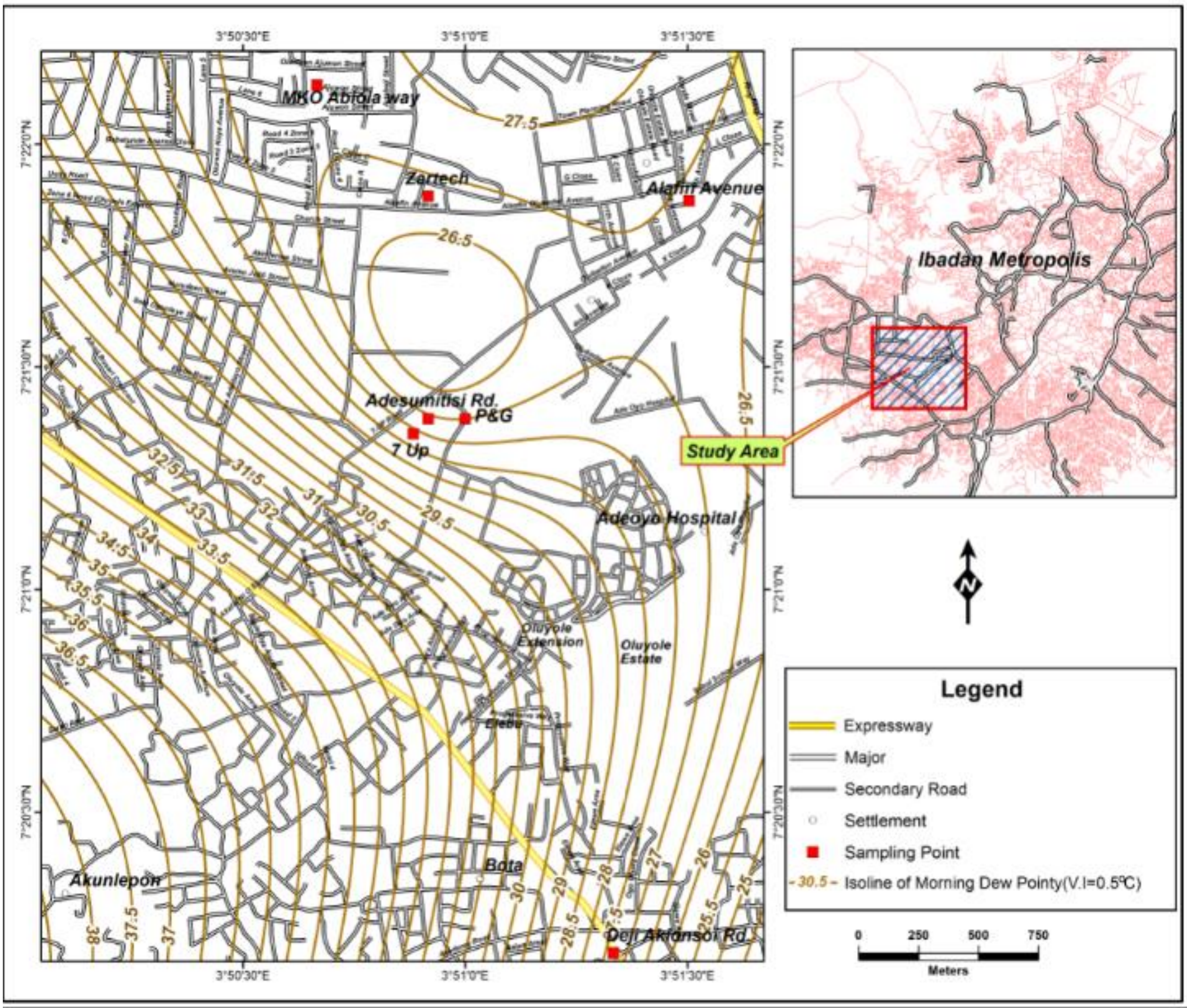

Figure 3b. Spatial variations in dewpoint temperature at morning time (06 – 10 NLST) over Oluyole Estate in Ibadan, Oyo State

4.2. Spatial and temporal variations

Evaluation of the spatial distribution of the selected indices showed warmer skin condition in the morning and afternoon than in the evening (Figure 4). In general, the minimum heat index values correspond to minimum air temperature, air temperature, dew point temperature in four separate linear regression models as follows:

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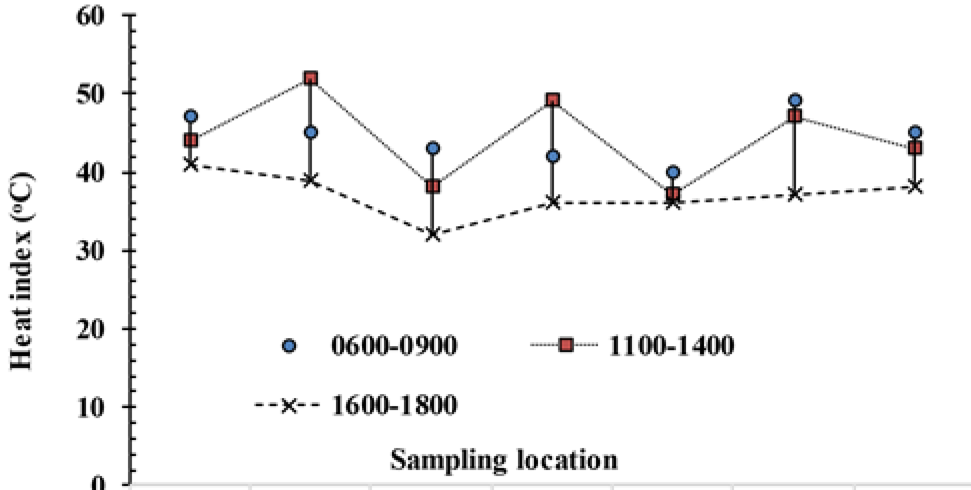

	S1	S2	S3	S4	S5	S6	S7
0600-0900	47	45	43	42	40	49	45
1100-1400	44	52	38	49	37	47	43
1600-1800	41	39	32	36	36	37	38

Figure 4. Variations in heat index values at the different stations around Oluyole Industrial Estate, Ibadan, Nigeria.

$HI = 17.86 + 1.05\ (Dp)$ (i)

$HI = -24.83 + 1.06\ (Dp) + 1.21(aT)$ (ii)

$HI = -60.86 - 0.1\ (Dp) + 2.42\ (aT) + 0.39\ (rH)$ (iii)

$HI = -57.85 + 2.31(aT) + 0.36\ (rH)$ (iv)

Equations i – iv were all significant at $p < 0.05$.

aT, rH, Dp and HI = air temperature (°C), relative humidity (%), dew point temperature (°C) and heat index (°C), respectively.

The results also showed stronger relationship between *Dp* and *HI* than among the other parameters (v – viii).

$aT = 25.98 + 0.22\ (HI)$ $(p = 0.02)\ (R^2 = 0.26)$ (v)

$rH = -3.27 + 1.30\ (HI)$ $(p = 0.01)\ (R^2 = 0.23)$ (vi)

$Dp = -4.61 + 0.66\ (HI)$ $(p = 0.003)(R^2 = 0.69)$ (vii)

aT, rH, Dp and HI = air temperature (°C), relative humidity (%), dew point temperature (°C) and heat index (°C), respectively.

The low strengths of relationship with *aT* and *rH* with *HI* are not surprising since though *aT* and *rH* are known to exhibit converse relationship, both relate with dew temperature and heat index in a similar pattern (Figure 5). Figure 5 also shows that the relationship between air temperature, dewpoint temperature and heat index do not produce same result with the relationship between relative humidity and dewpoint temperature and heat index, however. The results further indicate that rather than either the air temperature or relative humidity, dewpoint temperature is a better indicator of heat index.

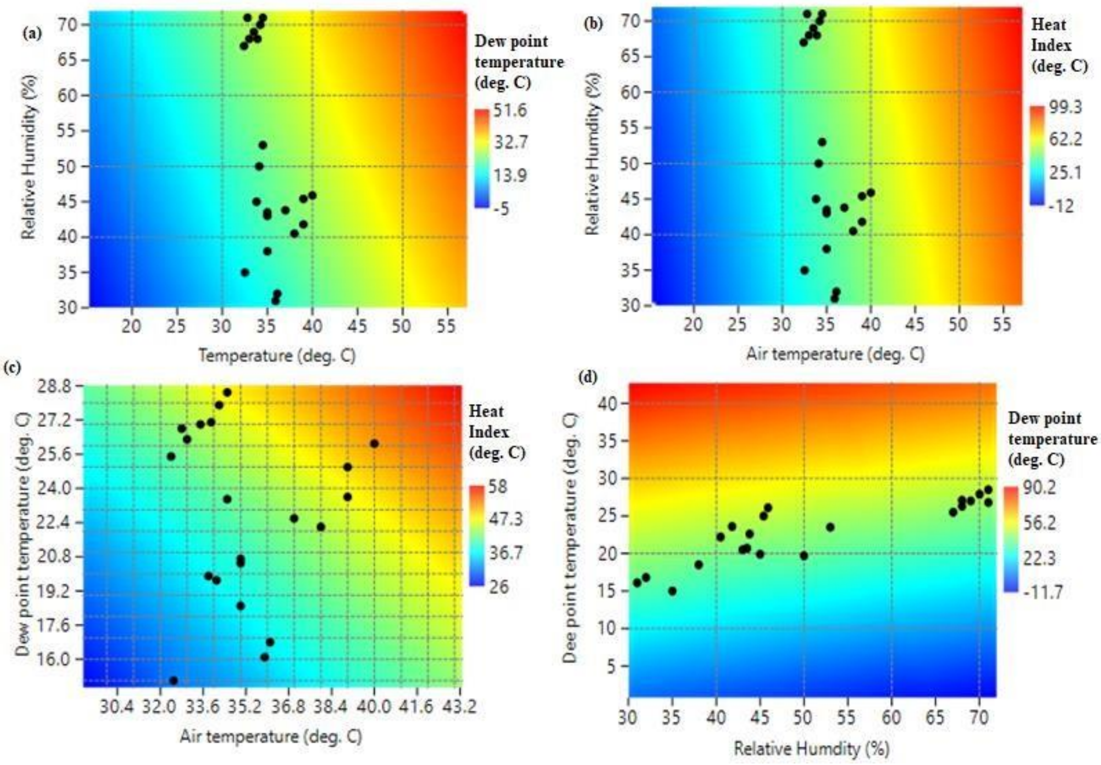

Figure 5. Relationships among selected heat indices

This result collaborates the perception that integrative indices rather than the unitary heat elements such as air temperature, relative humidity or radiant alone, are better measures of thermal climate of a region (Matzarakis, 2001; Gomez et al., 2004; Eludoyin and Adelekan, 2013)

5. SUMMARY AND CONCLUSION

The study examined selected thermal comfort indices over Oluyole Industrial region in Ibadan, Oyo State, Nigeria. The study of urban climate has generated significant interest since the observations of UHI in many urban areas. Studies on UHI also showed that industrial regions are equally prone to increase in temperature, apart from the vulnerability of the residents to air and noise pollution. In many industrial areas in Nigeria, there is little or no concern for temperature increase which studies have linked to thermal discomfort, heat wave and associated sickness including heat rash, stroke and even sudden death due to hydration. Although there has not been records of major heat-related death in the study area, it is difficult to conclude as not all severe sickness or even deaths are investigated in the country. Nonetheless, given the evidence of warmer condition in the industrial region, it is recommended that urban greening policy – involving planting of trees, including ornamental plants for both beautification and assimilation of the carbon emission from the industries, should be encouraged. Efficient monitoring of the ecosystems of industrial centres in the country should also be focused for periodic evaluation of the impact of the industrial activities. In all, the study concluded that residents in the industrial region are likely to feel warmer than the ambient air temperature, and this is associated with the effect of the industrial activities in the area as explained by the heat island concept.

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