Computerized Modeling of Aerosol Effects on the Thermal Comfort in the Urban Climate of Ilorin-Nigeria

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Abstract

Urban thermal comfort is higher than the rural due to massive anthropogenic activities. The uncontrolled injection of aerosols from industrial waste emission, decay of matter, biomass burning has its collective effect on the thermal comfort of the urban climate. The research site i.e. Ilorin, Nigeria is located in the middle of the Guinean zone coastline and Sudano-Sahelian zone. Thirty years (1981-2012) data set from the Nigerian Meteorological Center was obtained for the study. Thermal comfort was statistically analyzed using three key parameters i.e. surface temperature, relative humidity and hours of sunshine. Two crucial factors were seen to affect the thermal comfort of the study site i.e. regional climate and aerosol emission volume. The aerosol emission volume was analyzed using the AERONET satellite data set. A mathematical model was propounded to further the forecast of aerosol distribution and the equivalent effect on the thermal comfort of the region. The mathematical experimentation was done using the surfer tool and MATLAB. Four months i.e. November, December, January and February was discovered to be detrimental to people having respiratory or circulatory health challenges. This is because of the connection between thermoregulatory mechanisms and the circulatory/respiratory system.

Keywords: aerosol injection, thermal comfort, weather, numerical analysis, weather parameter, temperature, relative humidity, sunshine hour, model

1 Introduction

Thermal comfort in the urban settings of the tropics is gradually becoming a
significant challenge—largely due to increased anthropogenic activities [1, 2]. Its direct effect on thermal comfort is confirmed by the accumulation of atmospheric aerosol particles in the troposphere and stratosphere. Atmospheric aerosol particles have direct radiative forcing because of their ability to absorb or scatter solar and infrared radiation in the atmosphere. The variability of aerosols in the atmosphere makes it difficult to quantifying the aerosol radiative forcing which is believed to have either positive or negative climatic influence—depending on the aerosol size, life-time, complex refractive index, stoichiometry/composition and aerosol solubility. Hence, the global circulation system greatly influences the localization of aerosol in the troposphere and stratosphere. One of the major challenges facing scientist (about the aerosol) is the inability to adequately estimate—aerosol distribution, aerosol-cloud interactions, physical and chemical properties. The relationship between the thermal comfort and the aerosol deposition can be easily done via quantitative model. However, the reliance on the quantitative model may also be questionable because of the natural dynamism of aerosol. Hence, a mathematical model would be more adequate if the consistency of the aerosol distribution is known and its longwave influence on the thermal comfort are established. Many researches [3-6] have shown that the sensible heat flux from the earth is dangerous to life forms because it aids contagious diseases.

2 Research Site and its Atmospheric Features

Ilorin, south-west Nigeria, is characterized by monsoon features like distinct seasonal shift in the prevailing winds, alternation between winter dry conditions and summer rainy conditions [7]. It experiences dry northeasterly winds coming from the Sahara Desert during the winter. This experience leads to drastic reduction in rainfall. During summer season, Ilorin experiences low-level southwesterly winds and high rainfall rates [8]. In the lower troposphere (LT) of Ilorin, the wind flow is characterized by the south-westerly while the upper troposphere (UT) is characterized by the Tropical Easterly Jet [9]. Thermal comfort is determined or estimated by the measurement of key climatic factors like relative humidity, surface temperature, sun shine duration, wind speed e.t.c. Recall we had discussed other influences—order than climatic. Thermal comfort is also known as physiological equivalent temperature and could be defined as the equivalent effect of the degree of hotness or coldness on life forms. Here, we refer to the hotness noticed in the tropics. Significant study was performed for the average of each month to investigate the thermal comfort and the salient twist of both regional and global climate change.

Ilorin, Nigeria is located in the middle of the Guinean zone coastline and Sudano-Sahelian zone. Sudano-Sahelian zone is a region where average annual precipitation ranges from 500 to 900 mm. Guinean zone is a region where average annual precipitation exceeds 1100 mm. Hence, it is constantly between the influence of the tropical easterly and westerly Jet.
3 Assimilation of Ground and Satellite data set
The ground data set was obtained from the National Metrological Center and the satellite data set is obtained from the AERONET. The thermal comfort was simulated using three parameters i.e. surface temperature, relative humidity and hours of sunshine. In this paper, we understudy the consistency of thirty years (1981-2012) ground data set of key thermal comfort parameters.

The aerosol optical depth for the Ilorin and the correspondence activity at each sub-tropospheric layer is shown in figure 1-2. The statistical analysis of the thermal comfort in Ilorin is shown in Table 1. The sub-tropospheric layers were viewed from five parameters i.e. zenith angle, layer mode, layer central value, central point of pixel row and layer sub-setting points. The aerosol optical depth (AOD) had sinusoidal rise to its peak in 2006. After 2006, there is a sinusoidal drop which extends to 2014. The cause of the sudden sinusoidal drop was further analyzed via the activity at each sub-tropospheric layer. The zenith angle in 2012 and 2013.

The regional climate enforces the Platykurtic distribution on the thermal comfort as shown in Table 1-3. This signifies the challenges of modeling thermal comfort in this region-quantitatively.

![Figure 1: Aerosol Optical Depth analysis for Ilorin](image-url)
Figure 2: Activity at each sub-tropospheric layer

Table 1: Temperature (K) Data 1981-2012

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
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<th>Oct</th>
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<tbody>
<tr>
<td>Minimum</td>
<td>18.3</td>
<td>20.8</td>
<td>20.8</td>
<td>22</td>
<td>21.1</td>
<td>21.1</td>
<td>20.6</td>
<td>20.3</td>
<td>20.6</td>
<td>20.6</td>
<td>21</td>
<td>21.4</td>
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<tr>
<td>Maximum</td>
<td>24.3</td>
<td>24.5</td>
<td>26.3</td>
<td>24.8</td>
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<td>22.6</td>
<td>22.3</td>
<td>22.3</td>
<td>23.5</td>
<td>24</td>
<td>21.4</td>
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</tr>
<tr>
<td>Mean</td>
<td>21.82</td>
<td>23.02</td>
<td>23.5</td>
<td>23.1</td>
<td>22.51</td>
<td>22.18</td>
<td>21.21</td>
<td>20.12</td>
<td>20.02</td>
<td>20.77</td>
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<td>Variance</td>
<td>1.915</td>
<td>0.8037</td>
<td>0.7042</td>
<td>0.3687</td>
<td>0.6716</td>
<td>0.2673</td>
<td>0.2118</td>
<td>0.3477</td>
<td>0.5906</td>
<td>0.8791</td>
<td>0.9765</td>
<td>0.9376</td>
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<td>Standard deviation</td>
<td>1.384</td>
<td>0.8965</td>
<td>0.8392</td>
<td>0.6072</td>
<td>0.8195</td>
<td>0.4362</td>
<td>0.517</td>
<td>0.4603</td>
<td>0.4846</td>
<td>0.5897</td>
<td>0.7685</td>
<td>0.9376</td>
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<td>0.03894</td>
<td>0.03571</td>
<td>0.02628</td>
<td>0.03641</td>
<td>0.01974</td>
<td>0.0238</td>
<td>0.0149</td>
<td>0.02073</td>
<td>0.02673</td>
<td>0.03386</td>
<td>0.04236</td>
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<td>-0.413</td>
<td>1.203</td>
<td>-0.04</td>
<td>2.566</td>
<td>0.56</td>
<td>-0.579</td>
<td>-0.081</td>
<td>-0.583</td>
<td>0.429</td>
<td>0.096</td>
<td>-0.508</td>
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<td>Kurtosis</td>
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<td>3.253</td>
<td>2.397</td>
<td>10.309</td>
<td>1.624</td>
<td>1.79</td>
<td>0.274</td>
<td>0.041</td>
<td>0.437</td>
<td>-1.344</td>
<td>-0.326</td>
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<tr>
<td>Kolmogorov-Smirnov stat</td>
<td>0.104</td>
<td>0.091</td>
<td>0.203</td>
<td>0.154</td>
<td>0.202</td>
<td>0.123</td>
<td>0.106</td>
<td>0.133</td>
<td>0.132</td>
<td>0.122</td>
<td>0.166</td>
<td>0.103</td>
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Table 2: Relative Humidity Data 1981-2012

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>37</td>
<td>30</td>
<td>44</td>
<td>69</td>
<td>74</td>
<td>78</td>
<td>80</td>
<td>82</td>
<td>83</td>
<td>50</td>
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<td>36</td>
</tr>
<tr>
<td>Maximum</td>
<td>80</td>
<td>76</td>
<td>75</td>
<td>81</td>
<td>82</td>
<td>86</td>
<td>92</td>
<td>92</td>
<td>89</td>
<td>88</td>
<td>84</td>
<td>76</td>
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<tr>
<td>Mean</td>
<td>55.3</td>
<td>58.3</td>
<td>66</td>
<td>74.4</td>
<td>79.4</td>
<td>83</td>
<td>85.8</td>
<td>86.7</td>
<td>86.2</td>
<td>81.2</td>
<td>72.1</td>
<td>59.1</td>
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<tr>
<td>Variance</td>
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<td>204</td>
<td>68.4</td>
<td>9.8</td>
<td>5.43</td>
<td>5.45</td>
<td>6.42</td>
<td>7.4</td>
<td>7.29</td>
<td>50.6</td>
<td>57.8</td>
<td>147</td>
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<tr>
<td>Standard deviation</td>
<td>11.7</td>
<td>14.3</td>
<td>8.27</td>
<td>3.13</td>
<td>2.33</td>
<td>2.54</td>
<td>2.53</td>
<td>2.72</td>
<td>1.67</td>
<td>7.12</td>
<td>7.8</td>
<td>12.1</td>
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<tr>
<td>Coefficient of variation</td>
<td>0.21237</td>
<td>0.24494</td>
<td>0.12528</td>
<td>0.01206</td>
<td>0.02935</td>
<td>0.02814</td>
<td>0.02953</td>
<td>0.03136</td>
<td>0.01973</td>
<td>0.08761</td>
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<tr>
<td>Skew</td>
<td>0.185</td>
<td>-0.604</td>
<td>-1.346</td>
<td>-0.083</td>
<td>-0.852</td>
<td>-0.891</td>
<td>0.14</td>
<td>0.411</td>
<td>-0.365</td>
<td>-4.137</td>
<td>-1.075</td>
<td>-0.331</td>
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<tr>
<td>Kurtosis</td>
<td>-0.564</td>
<td>-0.731</td>
<td>1.49</td>
<td>-0.292</td>
<td>-0.12</td>
<td>-0.132</td>
<td>1.449</td>
<td>-0.304</td>
<td>-0.575</td>
<td>18.738</td>
<td>0.438</td>
<td>-0.742</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov stat</td>
<td>0.157</td>
<td>0.141</td>
<td>0.164</td>
<td>0.119</td>
<td>0.19</td>
<td>0.239</td>
<td>0.255</td>
<td>0.108</td>
<td>0.154</td>
<td>0.334</td>
<td>0.232</td>
<td>0.12</td>
</tr>
</tbody>
</table>

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3 Model Formulations

From the aerosol advection-deposition model established by Emetere [1, 2], the volume of the aerosol in Ilorin can be estimated.

\[ C(x, y, z) = a^2 b \cos \left( \frac{n}{k_x} y + \alpha \right) \cos \left( \frac{n}{k_z} z + \beta \right) \exp \left( \frac{n^2}{V_x} \right) \]  

(1)

\( a, b, n, \alpha, \) and \( \beta \) are constants that would be determined via remotely sensed data set. \( C(x, y, z) \) is the mean concentration of diffusing pollutants of diffusing substance at a point \((x, y, z)\) [kg/m\(^3\)]. \( Ky, Kx \) is the eddy diffusivities in the direction of the \( y \)-and \( z \)-axes [m\(^2\)/s]. Equation [1] represents three occurrences i.e. diurnal, sinusoidal flux of the aerosol content \((b \cos \left( \frac{n}{k_y} y + \alpha \right))\), vertical profile of aerosol content \((a \cos \left( \frac{n}{k_z} z + \beta \right))\) and dynamics of the aerosol content \((a \left[ \exp \left( \frac{n^2}{V_x} \right) \right])\).

The sinusoidal flux of the aerosol content is related to thermal comfort by the drag constant \((b)\). Hence, the incorporation Reynolds number is inevitable. Emetere [10] proved that in systems like PBL where multi-physics exist, the Reynolds number is not appropriate were convective activity is predominant. He came with the Unified number \((U)\) which governs the convective phenomena between two interacting fluids that are separated by a conductive medium. Mathematically, \( U \) is the unified parameter and it is defined as

\[ U = \frac{\rho C_p u_a}{h} \theta \]  

(2)

\( C_p \) is specific heat at constant-pressure, \( \rho \) is the density, \( U_a \) is the mean velocity of air, \( h = 0.4 W/mK \) for fluids (Emetere, 2014).

\[ \theta = \frac{\tau_{eq} - \tau_a}{\tau_f - \tau_a} \]  

(3)

Equation (3) is the dimensionless parameter for temperature which expresses...
the scale or magnitude of the temperature gradient of the fluid with respect to the pipe wall. \( T_0 \) is the initial temperature of the fluid, \( T_{eq} \) is the temperature profile/gradient between the fluid. The sinusoidal flux of the aerosol content can be therefore be written as

\[
\xi \approx b \cos\left(\frac{n}{k_y} + \alpha\right) \times U
\]  

(4)

From the Tables 1-3, the three weather parameters which determines the thermal comfort of an area can be related to

\[
\Gamma = \gamma \frac{T_t}{H_R}
\]

(5)

Here \( T \) is the surface temperature, \( t \) is the sunshine hour, \( H_R \) is relative humidity, \( \gamma \) is the balancing constant which defers according to location and have a unit m/Ks. In practice, the aerosol optical depth is calculated as [11]

\[
\tau(\lambda, j) = \sum_{i=1}^{n} Q_i (\lambda, r_i) n(r_i) d\gamma
\]

(6)

Here, \( n(r_i, j) \) represents the aerosol number concentrations, \( d\gamma \) is the height of the j-th atmospheric layer, \( Q_i \) extinction efficiency, \( a \) represents the aerosol particles in all of size bins and \( r_i \) is the particle’s wet radius. By definition, \( \frac{\xi}{U} \approx \sum_{i=1}^{n} Q_i (\lambda, r_i) n\gamma \). Hence,

\[
\xi \approx \frac{\tau(\lambda, j) U}{n(r_i, j) d\gamma}
\]

(7)

Hence, the computerized model is hinged on the sum of equation (5) & (7).

4 Demonstration of the Computerized Model

Using the satellite and ground data set given above, the thermal comfort for each month is displayed as shown in Figure 3. The geometrical transition of the thermal comfort between November to February shows that people with respiratory health challenges have low survival during the months of November, December, January, February, March and possibly April. This is because of the connection between thermoregulatory mechanisms and the circulatory/respiratory systems are more related to regional climate and atmospheric aerosol volume. Also, the relation between the thermal comfort parameters depends on the high atmospheric updraft and less downdraft. The strategic location of Ilorin gives it access to dry northeast wind and moist southwest wind which influences thermal comfort.
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Reference


