Evaluation of Simulated Noise Levels through the Analysis of Temperature and Rainfall: A Case Study of Nairobi Central Business District

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Abstract

There has been increasing noise levels all over the world in the last decade. Many factors contribute to this increase, which is causing health related effects to humans. Developing countries are not left out of the whole picture as they are still growing and advancing their development. Motor vehicles are increasing on urban roads; there is an increase in infrastructure due to the rising population, increasing number of industries to provide goods and so many other activities. All this activities lead to the high noise levels in cities. This study was conducted in Nairobi’s Central Business District (CBD) with the main objective of simulating noise levels in order to understand the noise exposed to the people within the urban area, in relation to weather parameters namely temperature, rainfall and wind field. The study was achieved using the Neighbourhood Proximity Model and Time Series Analysis, with data obtained from proxies/remotely-sensed from satellites, in order to establish the levels of noise exposed to which people of Nairobi CBD are exposed to. The findings showed that there is an increase in temperature (0.1°C per year) and a decrease in precipitation (40 mm per year), which in comparison to the noise levels in the area, are increasing. The study also found out that noise levels exposed to people in Nairobi CBD were roughly between 61 and 63 decibels and has been increasing, a level which is high and likely to cause adverse physical and psychological effects on the human body in which air temperature, precipitation and wind contribute so much in the spread of noise.

As a noise reduction measure, the use of sound proof materials in buildings close to busy roads, implementation of strict laws to most emitting sources as well as further research on the study was recommended.

The data used for this study ranged from the year 2000 to 2015, rainfall being in millimeters (mm), temperature in degrees Celsius (°C) and the urban form characteristics being in meters (m).

Keywords: Simulation, Noise Exposure, Weather, Proxy, Urban Planning, Nairobi

1.0 Introduction

There is an unequal urban growth which is taking place all over the world but the rate of urbanization is very fast in the developing countries. In 1800, only 3% of the world's population lived in urban centers but this figure reached to 14% in 1900 and in 2000, about 47% (2.8 billion) people were living in urban areas (United Nations Population Division, 2001).

In 1906, Nairobi being only a small town then, had a population of 11,512 people with a population density of 635 people per kilometer square. By 2015, the same town having the same size (696 Km²) has a population of around 4 million people with a population density of around 4000 people per kilometer square, with a projection of around 5 million by 2030 (City of Nairobi Environment Outlook Report, 2008).

The major cause of this growth is the search for better employment opportunities in these urban. As urban population increases, the demand of land for various urban activities also increases. The process of urbanization causes clearance of forests, drainage of wetlands and crop lands, encroachment of game parks, etc. under the influence of expanding cities, yet never as fast as in the last decade (Rahman and Netzband, 2007).

This rapid increase in ‘Population Growth’ has caused havoc for the human life in the city environment. Doubling and tripling of urban population practically in all major cities and towns and the consequent strain on the existing system manifested in an environmental chaos. An increasing number of trucks, buses, cars, tuk-tuks and motorcycles all spewing uncontrolled fumes and polluting the environment with noise, surge in sometimes-haphazard patterns over city streets jammed with jaywalking pedestrians (Gholami et al., 2012).

The phenomenon of accelerated urbanization is the main culprit, wherein besides bringing higher standard of living has also brought problems of growth of dense and unplanned residential areas, environmental pollution, non-availability of services and amenities and solid waste generation and growth of slums (Rahman and Netzband, 2007).

The level of pollution i.e. air, water, noise and land has increased because of poor environmental management. This has its direct impact on quality of urban environment, affecting efficiency of the people and their productivity in the overall socio-economic development (Rahman and Netzband, 2007).

Environmental noise is becoming a global concern as times goes by as most cities are still subjected to an increased noise levels which is becoming a significant factor affecting the well-being of people. Many studies have shown that noise is largely responsible for many physio-psychological effects in man (Björkman and Lercher, 1991).

It is considered a major cause of exogenous sleep disturbances, after somatic problems and day tensions. Apart from these measurable effects and the subjective feeling of disturbed sleep, people who struggle with nocturnal environmental noise often also suffer the next day from daytime sleepiness and tiredness, annoyance, mood changes as well as decreased well-being and cognitive performance (Muzet, 2007).

There is increasing evidence that quantitative and qualitative sleep disturbances may play a role in the development of cardio-metabolic disease. A number of cardiovascular risk factors and cardiovascular outcomes have been associated with disturbed sleep: coronary artery calcifications, atherogenic lipid profiles, atherosclerosis, obesity, type 2 diabetes, hypertension, cardiovascular events, etc. Increased mortality from all causes has also been observed (Tsaloglidou and Koukourikos, 2015).

Tabraiz et al (2015) found out that those most affected by high levels of environmental noise were traffic wardens due to the nature of their work. Some of the cases included hypertension, aggravated depression, muscle tension, low performance levels, concentration loss, hearing impairment and cardiovascular issues.

Urban planning within cities is one of the main goals of governments to reduce the increasing environmental noise and also as a key tool in providing good quality of life for its people. This can be achieved through an increase in urban spaces within cities despite it posing a great challenge to the planners (Torija et al, 2015).

In this context, this study was used to assess the levels of noise exposed to people working and living in Nairobi CBD, which can contribute substantially in a more supplementary fashion for assessing, understandings and solving complex urban environmental issues. By utilizing proxies and remote sensing data, noise levels can be detected over a period of time and environmental pollution can be understood (Ligia et al, 2013).
1.1 Objectives of the Study
The general objective was to simulate noise levels in relation to weather in the context of noise pollution in Nairobi’s Central Business District (CBD). In order to achieve the general objective, the specific objectives were as follows:

a) To determine the temporal patterns of temperature and rainfall over Nairobi’s Central Business District (CBD)
b) To assess the noise levels exposed to the people in Nairobi’s Central Business District (CBD)

1.2 Area of Study.
The area chosen for this study was Nairobi’s Central Business District (CBD), with coordinates 1°17’10”S, 36°49’16”E as shown in Figure 1.

2.0 Data and Methodology
2.1 Data
The data used in this study were rainfall and temperature reanalysis (2000 – 2015) obtained from the MERRA model from NASA’s satellites, as well as size of patches (areas and perimeters) obtained from the Neighborhood Proximity Model.

2.2 Methodology
The methods used were as follows:

a) Time Series Analysis
This was used in determining the temporal patterns of temperature and rainfall over Nairobi CBD. The data was arranged in R environment and analyzed to give the results in Figures 2-5.

b) The Compactness Index (CI)
This measures the shape of an urban patch and the fragmentation of the urban landscape. The Compactness index (CI) is calculated based on the following equation:

\[ CI = \frac{\sum \frac{i^2}{pi}}{n} = \frac{\sum i2\pi \sqrt{Si}/\pi}{n} \] ................................ (1)

Where \( S_i \) the patch area (m²), \( pi \) is patch perimeter (m), \( Pi \) is circle perimeter with an area \( S_i \) (m²) and \( n \) is total number of patches.

c) Porosity Index or Ratio of Open Space (ROS)
This measures the proportion of open space, compared to the total urban area. This is calculated from the Equation 2:

\[ ROS = \frac{s'}{\sum S_i} * 100 \] ................................... (2)

Where \( s' \) is the sum of area of all the open spaces within the urban studied area (m²) and \( S_i \) is patch area (m²).

d) The Complexity of the Perimeter Index (Fractal)
This index describes the complexity of the perimeter of an urban area through the relationship between perimeter and area. In this research, the average fractal dimension of urban patches weighted by the area was used.

\[ Fractal = \Sigma_{i=1}^{n} \left( \frac{2ln(P_i)}{2\pi} \right) \left( \frac{S_i}{\sum_{i=1}^{n} S_i} \right) \] ................................ (3)

Where \( S_i \) is the patch area (m²), \( Pi \) is patch perimeter (m) and \( n \) is number of patches.

3.0 Results and Discussion
3.1 Temporal patterns of temperature and rainfall over Nairobi CBD
The reanalysis data obtained from satellites were analyzed on R environment to give the following results.

Figure 1: Map showing Nairobi central Business District
(Source: Google earth, 2016)
3.1.1 Temperature Averages

The average temperature over Nairobi CBD was observed to have two high peaks (January to April, August to October) and two low peaks (May to July, November to December).

From Figure 2 and 3, it was discovered that temperature in Nairobi CBD is changing in a slow but steady pace. Noise is directly affected by temperature (Botteldooren and Timothy, 2010). During high temperature season, the levels of noise produced increased as they propagated further in the atmosphere. During the cold and rainy seasons, noise levels reduced due to low temperatures.

From the trend analysis, the temperature was observed to be rising at a rate of 0.1 degrees centigrade per year from 2000 to 2015 over Nairobi’s CBD.

With the increase in urban forms due to development, it can be predicted that by 2030 temperatures over Nairobi CBD will be higher than they are now, which will also mean that the levels of noise will be higher than the current state.

3.1.2 Rainfall Averages

This study found that the MAM and OND seasons had an observed high precipitation compared to other seasons of the year.

Results from the observed trend in Figure 5 showed that there has been a decrease in precipitation over Nairobi CBD only, at the rate of 40 millimeters per year since 2000 up to 2015. The amount of precipitation observed first rises with increasing air pollution. With time and at very high concentrations of the aerosols, precipitation decreases sharply as observed in Figure 4.

This is because in clean air, increasing aerosols in the atmosphere releases the maximum available energy which in turn increases precipitation at first. Beyond that, the increasing aerosols start to lessen precipitation to below normal and even lead to drought (Botteldooren and Timothy, 2010).

3.2 Assessment of noise levels exposed to the people in Nairobi CBD

The noise levels exposed to people in Nairobi CBD was assessed by Pedro’s Neighborhood Proximity Model using the urban forms given in Figure 6. The calculation of the form indicators was done by
ArcGIS using the data from Table 1 and the indices equations to give the exposed form indicators as a summary in Table 2.

Table 1 shows the physical characteristics of the ten selected urban forms in Figure 1, i.e. patch perimeter, area and number of patches. The forms 1 to 10 were indicated as letters (a) to (j) in Figure 1.

From the data in Table 1, the noise simulation model evaluated the noise level at different receiver points and at the facades of the real forms to be comparable with the real modeled form, which had a two-lane traffic volume of 167 vehicles per hour. The results were found as shown in Table 3.

<table>
<thead>
<tr>
<th>Urban Forms</th>
<th>Patch No</th>
<th>Patch area ($m^2$)</th>
<th>No of Patches</th>
<th>Patch Perimeter (m)</th>
<th>Radius circle (m)</th>
<th>Occupied Area ($m^2$)</th>
<th>Reference Area ($m^2$)</th>
</tr>
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<td>Form 1</td>
<td>Patch 1</td>
<td>2110.7</td>
<td>3</td>
<td>430.1</td>
<td>43.48</td>
<td>6332.1</td>
<td>24707.5</td>
</tr>
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<td>Form 2</td>
<td>Patch 1</td>
<td>1099.1</td>
<td>3</td>
<td>242.4</td>
<td>36.67</td>
<td>6355.8</td>
<td>24707.5</td>
</tr>
<tr>
<td></td>
<td>Patch 2</td>
<td>1012.8</td>
<td>3</td>
<td>227.2</td>
<td>35.7</td>
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<tr>
<td>Form 3</td>
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<td>3</td>
<td>430.1</td>
<td>43.48</td>
<td>5095</td>
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<td>248</td>
<td>42.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patch 3</td>
<td>1000.8</td>
<td>2</td>
<td>231.6</td>
<td></td>
<td>40.92</td>
<td></td>
</tr>
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<td>Form 4</td>
<td>Patch 1</td>
<td>1951.1</td>
<td>3</td>
<td>5853.2</td>
<td>447.83</td>
<td>5473</td>
<td>24707.5</td>
</tr>
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<td>Patch 1</td>
<td>560</td>
<td>3</td>
<td>135.8</td>
<td>28.64</td>
<td>5434</td>
<td>24707.5</td>
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<tr>
<td></td>
<td>Patch 2</td>
<td>521</td>
<td>3</td>
<td>128</td>
<td>26.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patch 3</td>
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<td>129.4</td>
<td>27.07</td>
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<td></td>
<td>Patch 4</td>
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<td>137.4</td>
<td>29.03</td>
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<td></td>
</tr>
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<td>Form 6</td>
<td>Patch 1</td>
<td>198.7</td>
<td>4</td>
<td>61</td>
<td>11.18</td>
<td>4317.6</td>
<td>24707.5</td>
</tr>
<tr>
<td></td>
<td>Patch 2</td>
<td>722.6</td>
<td>4</td>
<td>181.6</td>
<td>37.37</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Patch 3</td>
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<td>2</td>
<td>85.8</td>
<td>16.72</td>
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<td>Form 7</td>
<td>Patch 1</td>
<td>521</td>
<td>4</td>
<td>128</td>
<td>26.72</td>
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<td>133.7</td>
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<td>46.3</td>
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</tr>
<tr>
<td></td>
<td>Patch 3</td>
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<td>167.2</td>
<td>36.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patch 4</td>
<td>383</td>
<td>2</td>
<td>95</td>
<td>14.75</td>
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<td></td>
</tr>
<tr>
<td>Form 8</td>
<td>Patch 1</td>
<td>679</td>
<td>8</td>
<td>151.1</td>
<td>26.92</td>
<td>5432.1</td>
<td>24707.5</td>
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<td>Form 9</td>
<td>Patch 1</td>
<td>696.2</td>
<td>7</td>
<td>164.3</td>
<td>35.44</td>
<td>4873.4</td>
<td>24707.5</td>
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<td>Form 10</td>
<td>Patch 1</td>
<td>351.7</td>
<td>4</td>
<td>75</td>
<td>13.26</td>
<td>4803.3</td>
<td>24707.5</td>
</tr>
<tr>
<td></td>
<td>Patch 2</td>
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<td>4</td>
<td>101</td>
<td>15.8</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Patch 3</td>
<td>362</td>
<td>2</td>
<td>80.4</td>
<td>13.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patch 4</td>
<td>460</td>
<td>2</td>
<td>92.4</td>
<td>15.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6: Urban forms (a) 1, (b) 2, (c) 3, (d) 4, (e) 5, (f) 6, (g) 7, (h) 8, (i) 9 and (j) 10

Table 1: Physical characteristics of the selected urban forms.
Table 2: Summary of results of the calculation of the form indicators.

<table>
<thead>
<tr>
<th>Form Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>0.38</td>
<td>0.49</td>
<td>0.48</td>
<td>0.35</td>
<td>0.62</td>
<td>0.68</td>
<td>0.72</td>
<td>0.61</td>
<td>0.57</td>
<td>0.82</td>
</tr>
<tr>
<td>ROS (%)</td>
<td>74.37</td>
<td>74.36</td>
<td>80.38</td>
<td>76.31</td>
<td>78</td>
<td>82.53</td>
<td>80.55</td>
<td>78.01</td>
<td>80.28</td>
<td>80.56</td>
</tr>
<tr>
<td>Fractal</td>
<td>1.25</td>
<td>1.2</td>
<td>1.21</td>
<td>1.28</td>
<td>1.15</td>
<td>1.16</td>
<td>1.14</td>
<td>1.15</td>
<td>1.17</td>
<td>1.07</td>
</tr>
</tbody>
</table>

Table 3: Urban form indices vs. average noise level facades (traffic volume – 167 vehicles/h).

<table>
<thead>
<tr>
<th>Urban Form</th>
<th>Average Noise Level (dB)</th>
<th>CI</th>
<th>ROS (%)</th>
<th>Fractal</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>58.3</td>
<td>0.38</td>
<td>74.37</td>
<td>1.25</td>
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<tr>
<td>2</td>
<td>57.9</td>
<td>0.49</td>
<td>74.36</td>
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<td>3</td>
<td>60.8</td>
<td>0.48</td>
<td>80.38</td>
<td>1.21</td>
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<tr>
<td>4</td>
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<td>0.35</td>
<td>76.31</td>
<td>1.28</td>
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<tr>
<td>5</td>
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<td>0.62</td>
<td>78</td>
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</tr>
<tr>
<td>6</td>
<td>62.6</td>
<td>0.68</td>
<td>82.53</td>
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</tr>
<tr>
<td>7</td>
<td>63.8</td>
<td>0.72</td>
<td>80.55</td>
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<td>8</td>
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<td>0.61</td>
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<tr>
<td>9</td>
<td>64.6</td>
<td>0.57</td>
<td>80.28</td>
<td>1.17</td>
</tr>
<tr>
<td>10</td>
<td>64.5</td>
<td>0.82</td>
<td>80.56</td>
<td>1.07</td>
</tr>
</tbody>
</table>

Results of Table 3 were shown by the plots of various indices and the average noise levels, which can be seen in Figure 7.

It was observed that there was an increase in compactness index (CI), porosity index (ROS) and a decrease in complexity perimeter index (Fractal). This meant that the urban area, Nairobi CBD, had a regular and compact form as well as a higher ratio of open spaces which contributed to the increase in noise levels around CBD. The increase in complexity perimeter index indicated a decrease in noise levels which were attributed to the more complex and irregular patches selected for the study.

This is quite close to the Neighborhood proximity Model result, which found the level to be 63 dB, hence proving the level of accuracy of the model. The average noise level (Leq) over Nairobi CBD was found to be approximately 61 dB from a previous research using an analysis by Geographical Information Systems (GIS) (Wawa and Mulaku, 2015).

3.3 Effects of Wind Speeds on Noise
When wind speed increases with altitude, wind blowing towards the listener from the source will refract sound waves downwards, resulting in increased noise levels downwind of the barrier. Accelerated winds near very tall buildings, i.e., skyscrapers, are caused by the downdraught effect. The downdraught effect is most strong where buildings stand face-on to the prevailing wind.

This happens where the air hits a building and, with nowhere else to go, is pushed up, down and around the sides. The air forced downwards increases wind speed at street level.

There is also an acceleration of wind around the side of the buildings if it has completely square corners. If several towers stand near each other, there is an effect known as "channeling", a wind acceleration created by air having to be squeezed through a narrow space. This is a form of the Venturi effect.

Narrower roads concentrate the wind through channeling more than happens in wider streets and avenues. These different effects can combine to create faster-moving wind.

The speed of sound decreases with decreasing temperature, so this also creates a negative sound speed gradient. The sound wave front travels faster near the ground, so the sound is refracted upward, away from listeners on the ground, creating an acoustic shadow at some distance from the source.

Higher values of wind gradient will refract sound downward toward the surface in the downwind direction, eliminating the acoustic shadow on the downwind side. This will increase the level of sound downwind. There will usually be both a wind gradient and a temperature gradient. In that case, the effects of both might add together or subtract depending on the situation and the location of the observer (Botteldooren, 2010).

4.0 Conclusion

The study found out that noise levels exposed to people in Nairobi CBD were roughly between 61 and 63 decibels, a level which is high and likely to cause adverse physical and psychological effects on the human body.

The observed decreasing precipitation amount, at 40mm per year, in turn brings about an increase in temperature over Nairobi CBD which will in turn affects wind patterns. Wind speeds increase in height due to thermal pressure differences. The three are mutually related; hence a change in one will affect the other and cause a variation in noise pollution.

Vision 2030 will see the development of Kenya to new heights, which includes Nairobi’s Central Business District (CBD) improvements on infrastructure as well as an increase in population. This means that more urban spaces will be taken up by buildings and roads to pave way for the achievement of the vision. The levels of noise are hence expected to rise in the future as the number of cars and buses will increase owing to new technology and cheap prices for vehicles, as well as the presence of sky scrapers and a high population.

This increased noise levels will cause more harm to man’s health if left unattended, which will affect the economy in the long run.

4.1 Recommendation

- Buildings close to roads and highways should be constructed with sound proof material to reduce the noise levels inside them.

- Awareness and sensitization on the impacts of noise exposed to human beings.

- Review of the existing legislations in favor of mitigations related to existing and upcoming noise problems.

- Further research studies on environmental noise pollution in Nairobi CBD as well as all fast developing cities within the country.

Acknowledgements

The data used in this study, rainfall and temperature, were acquired as part of the NASA’s Earth-Sun System Division and archived and distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) Distributed Active Archive Center (DAAC).

References


