Dynamics of Wind Strength and Wind Direction on Air Pollution Dispersion

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ABSTRACT— *The aim of the study is to examine the wind dynamics of Ota to understand certain atmospheric influences. An average volume of about four hundred and eighty thousand (480,000) wind speed data from the Davis weather station data logger of the department of physics, covenant university were considered. The data studied were divided into eight hour period, namely, night time (10pm to 6am following day); day time (6am to 2pm) and noon/evening time (2pm to 10pm). Of the three periods studied, wind speed at night time was observed to be the least. December, January and February (DJF) data set was statistically analyzed. The correlation coefficient values recorded with the wind flow for the months of DJF are 0.28 for December, 2012, 0.20 for January, 2013, and 0.39 for February, 2013. While a significant low correlation coefficient values observed for the months of March, April and May (MAM) are 0.02 for March, 0.01 for April and 0.04 for May. A further daily analysis was conducted for February. A significant occurrence of atmospheric stagnation was observed in the night time readings of February 3, 2013 with an exceptional low average wind speed of 0.143 ms-1. While February 17, 2013 recorded all day normal air ventilation with wind speed of 1.443 ms-1, 1.998 ms-1, 4.482 ms-1 for night, day and noon/evening time respectively.*

Keywords— Wind speed and direction, atmospheric stagnation, air pollution

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1. INTRODUCTION

Prevailing atmospheric dynamics over a region determines if air pollution released into the atmosphere will be either critical or nominal. Air pollution is considered critical when it has serious short or long term threats on life-forms [1]. The wind pattern over an area is essential in determine pollution transport. For example, same concentration and volume of air pollution that lead to episodic occurrence over an area may barely get noticed over another region depending on the rate of dispersion and diffusion [2]. Atmospheric ventilation, stagnation and recirculation are air flow conditions that either aid or hinder quick dispersion [3]. Poor vertical air mixing and minimum horizontal air flow- coupled with minimum or zero precipitation leads to accumulation of air pollutants over a period of time. Air movement can dilute and remove pollutants. Pollutant dilution depends on the wind velocity and the air stability (lapse rate). Wind speed ratio is used to define atmospheric stability [4]. The safety classification is shown in Table 1.

Table 1: Wind Speed Ratio Classification [5]

Stability Class	Wind Speed Ratio range (U_R)
A	$U_R < 1.18$
B	$1.18 \leq U_R < 1.21$
C	$1.21 \leq U_R < 1.26$
D	$1.26 \leq U_R < 1.56$
E	$1.56 \leq U_R < 2.28$
F	$2.28 \leq U_R < 3.28$
G	$U_R \geq 3.28$

We propose that the directional wind speed determines the plume dispersion that is dominant at particular duration. The role of atmospheric dynamics through the study of wind data was the focus of this paper. Several factors can influence atmospheric instability in the tropics. The influencing factor is solar activity which drives updraft and downdraft. Buoyancy induced wind motion could be observed to account for the excess of the day time wind motion over the night time's. Wind speed and wind direction play major roles in the transport and dispersion of air pollutant [6]. Air pollution emission can be on various scales ranging from micro-scale such as emission from industrial stack, synoptic scale such as cross- border / cross continent transport of air pollutants. In this paper, we examine the wind activity over Ota, Nigeria to ascertain the wind trend for air pollution control measures. This result is important for necessary application in the aviation industry, disease control agency, pollution control unit and metrological research.

2. THEORETICAL BACKGROUND OF THE STUDY

Analysis of aerosol dispersion was transformed from ID- model [7] known as the fractional advection dispersion equation (FADE) to 2D –model [8]. The 3D-model was propounded by [1] with a solution written mathematically as

$$C(x,y,z) = a^2 b\cos\left(\frac{n}{k_y} + \alpha\right)\cos\left(\frac{n}{k_z} + \beta\right)\exp\left(\frac{n^2}{V_x}\right) \qquad (1)$$

Here, C(x,y,z) is the mean concentration of diffusing pollutants of diffusing substance at a point (x,y,z) [kg/m^3], k_y, k_x is the eddy diffusivities in the direction of the y- and z- axes [m^2/s] .
b,n, α, and β are constants that may also be determined via remotely sensed data set. The practical application of equation (1) is explained in the next session. Equation (1) represents three occurrences i.e. diurnal, sinusoidal flux of the aerosol content ($b\cos(\frac{n}{k_y} + \alpha)$), vertical profile of aerosol content ($a\cos(\frac{n}{k_z} + \beta)$) and dynamics of the aerosol content ($a[\exp\left(\frac{n^2}{V_x}\right)]$). Since the main objective is to determine the role of atmospheric dynamics in air pollution dispersion in the Tropospheric column in the tropics. This helps us to determine the lapse rate amongst other salient parameters. Hence, we are more interested in equation as it describes the role of atmospheric dynamics in air pollution dispersion.

$$\tau = a\left[\exp\left(\frac{n^2}{V_x}\right)\right] \qquad (2)$$

where n is the isothermal lapse rate. a is the frequency of automatic weather station.

3. METHODOLOGY

An average volume of about four hundred and eighty thousand (480,000) wind speed data from the automatic weather station (Davis Pro 2) data logger of the Department of Physics, Covenant University were considered. The location of study is on latitude 6.7^o and longitude 3.23^o. The data studied were divided into eight hour period, namely, night time (10pm to 6am following day); day time (6am to 2pm) and noon/evening time (2pm to 10pm). Two quarter of the year was also considered namely: December, January, February (DJF) and March, April, May (MAM)

4. RESULTS AND DISCUSSION

The magnitude of each wind direction and its corresponding wind speed from December to February (DJF) is shown in Table 2. This period is majorly influenced by the north-east wind which brings harmattan dust. A constant wind speed of 4m/s blows south towards the hall of residence and staff quarters were about 6,000 persons reside. Should there be a major outbreak of air pollution during December; life-forms would be massively affected. In January, a constant speed of 7.2 m/s blew west-towards the forest area of Iju (a settlement close to Covenant University). In February, a constant speed of 7.2 m/s and 7.6 m/s blew southwest and west respectively-towards the forest area of Iju (a settlement close to Covenant University).

Table 2: Data of the wind direction for the DJF

Wind Direction	Max. Wind Speed (m/s)	No of corresponding Data	Max. Wind Speed (m/s)	No of corresponding Data	Max. Wind Speed (m/s)	No of corresponding Data
	December		January		February	
SE	2.2	14	6.3	156	5.4	128
S	4	29131	6.3	121	6.7	250
NW	4.9	75	6.7	2554	6.3	2421
NNW	6.7	20	4.5	919	3.1	531
NE	3.6	21	4.5	1168	4.0	1389
N	4	1536	4	1536	-	-
ESE	4.5	85	5.8	494	3.6	374

ENE	4	60	5.8	148	4.5	3398
NNE	4.5	42	4.5	721	3.6	601
E	4.5	530	4.5	294	4.5	1681
WSW	4	244	7.2	3293	7.2	6391
WNW	2.7	92	7.2	2284	6.7	2867
W	3.6	367	7.6	4908	7.6	5900
SW	3.1	222	5.8	700	5.8	1694
SSW	2.7	63	4.5	153	8.5	234
SSE	-	-	6.7	70	6.3	129

The interpretation of table 2 is shown in figure 1and 2 below. Why should the wind blow towards the settlement in December and blow away from the settlement in January and February? The air mixing state follows the simple rule of both pressure and temperature difference [9]. Also the topography of the area influences the wind pattern [10]. A daily investigation into the wind pattern was imminent to ascertain the kind of variability the region (Ota) possesses. From literature [11], a daily analysis of February is essential because of the peculiarity of the West Africa monsoon.

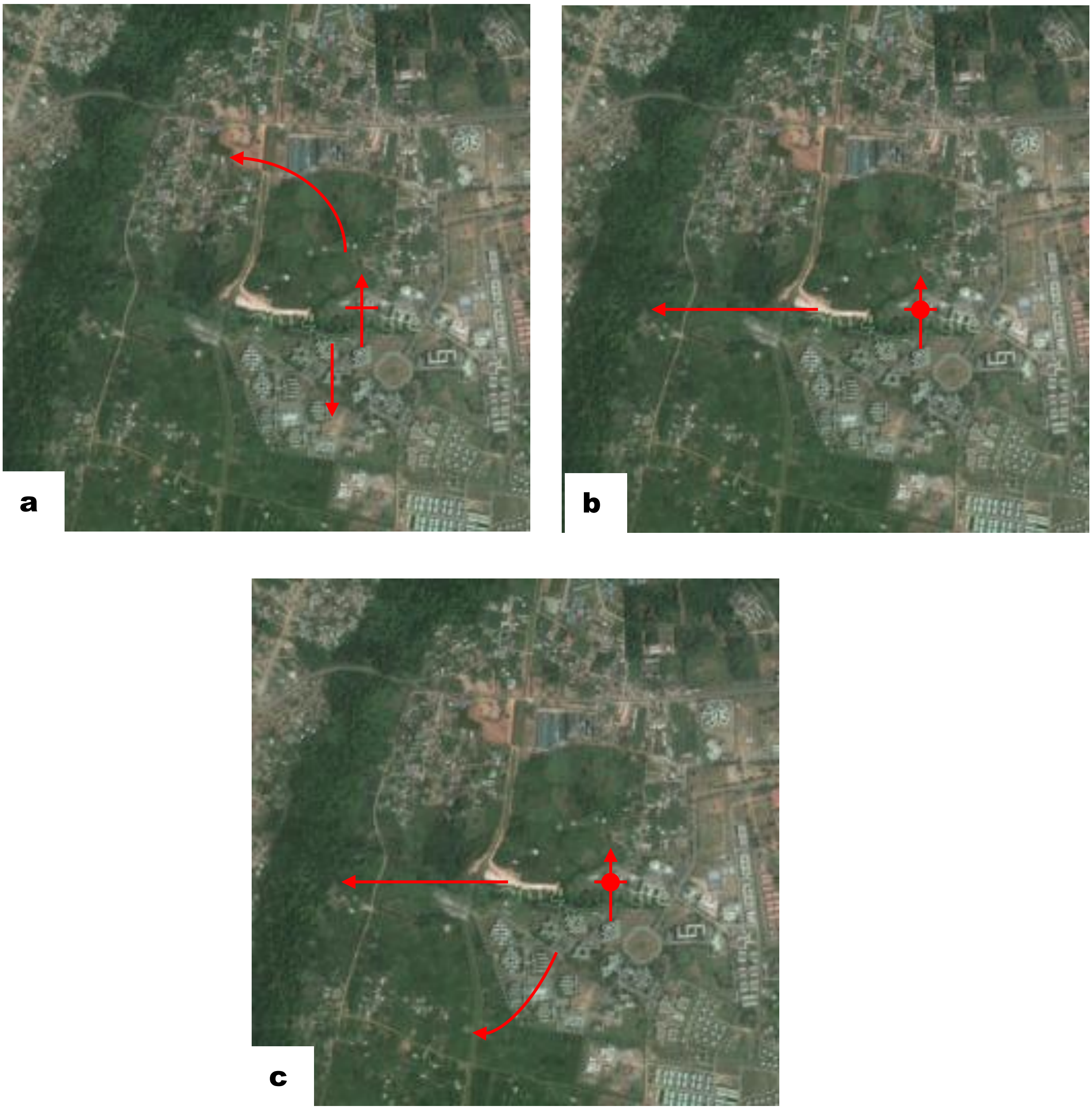

Figure 1a: wind direction in December; figure 1b: wind direction in January;
Figure 1c: wind direction in February

Figure 2 depicts results in form of wind speed observations for months of December 2012 and January and February 2013 stagnation events in all wind direction. The result clearly shows that the city of Ota is prone to stagnation in all wind direction throughout the period of study. The month of January and February 2013 was observed in most cases high stagnation wind speed in all wind direction. It is important to note that February recorded the highest wind speed of about 8.5 ms^{-1} in South South West (SSW) wind direction. Ota, been located in southwest observed high wind speed for February in all South and West wind direction with minimum of 3.1 ms^{-1} in North North West (NNW). However, no wind speed was recorded in North (N) direction throughout the month of February. This may be as a result of low or calm wind [12]. Stagnation conditions in January was similar to that of February revealing high wind speed in all direction under the range of about 4.0 ms^{-1} in North (N) direction to 7.6 ms^{-1} in West (W) direction. December was observed to be low generally with prevalence of calm wind speeds supports it stagnation dominance in Ota. However, highest wind speed for December was noticed in North North West (NNW) direction of about 6.7 ms^{-1} and no wind speed measurement was observed on South South East (SSE) direction.

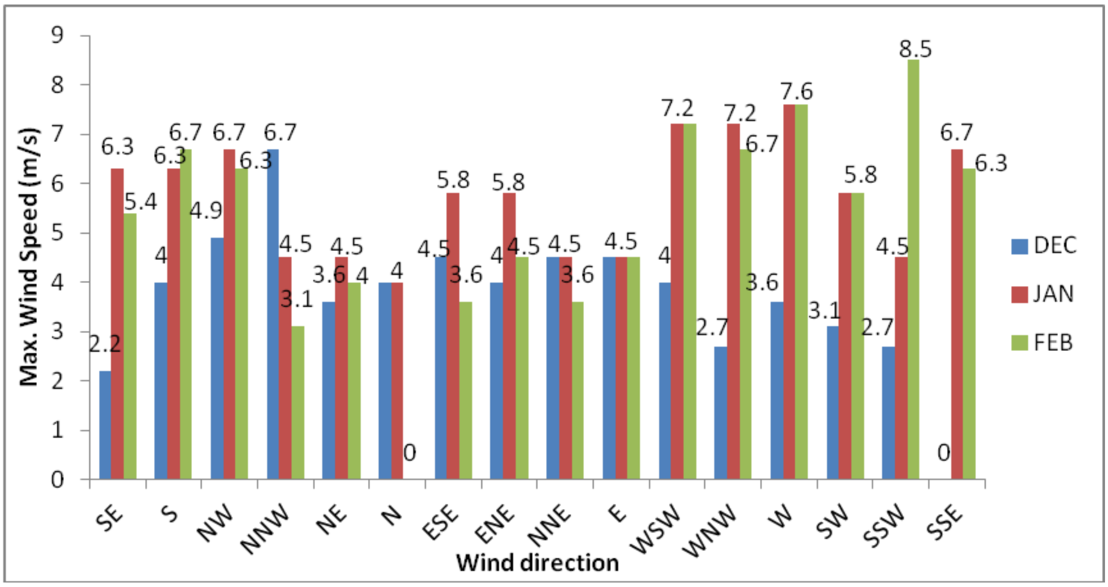

Fig. 2: Monthly wind speed of occurrence of stagnation events.

Figures 3 and 4 shows the scatter plots of daily wind speed from December, January and February (DJF) and March, April and May (MAM) respectively. It can be seen that distinct pattern and trends observed in DJF is obviously different from MAM, this may be attributed to the presence of atmospheric blocking which leads to stagnation of weather patterns in MAM [13]. The correlation coefficient values recorded with the wind flow for the months of DJF are 0.28 for December, 2012, 0.20 for January, 2013, and 0.39 for February, 2013. While a significant low correlation coefficient values observed for the months of MAM are 0.02 for March, 0.01 for April and 0.04 for May.

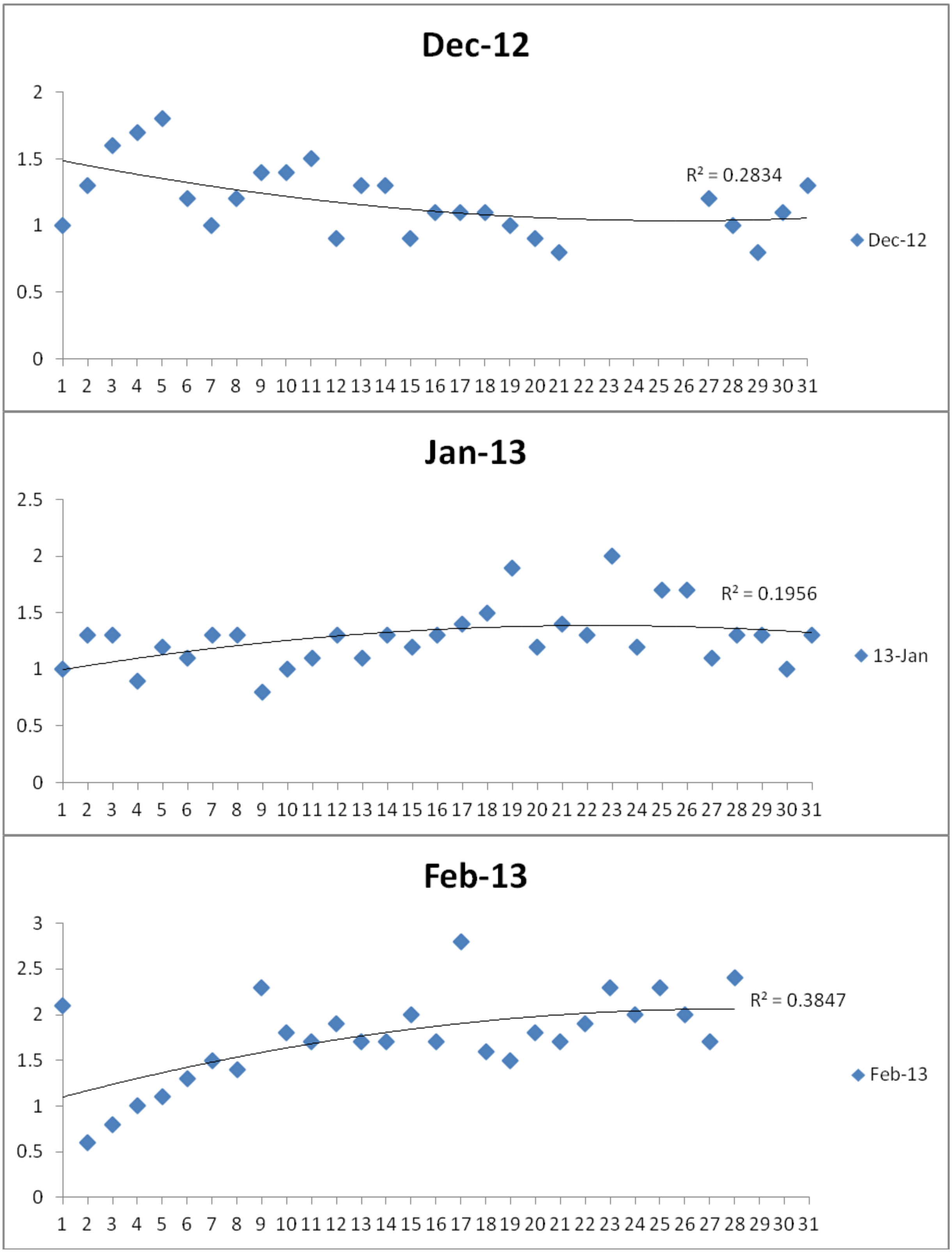

Figure 3: Scatter plots of daily wind speed from December to February (DJF)

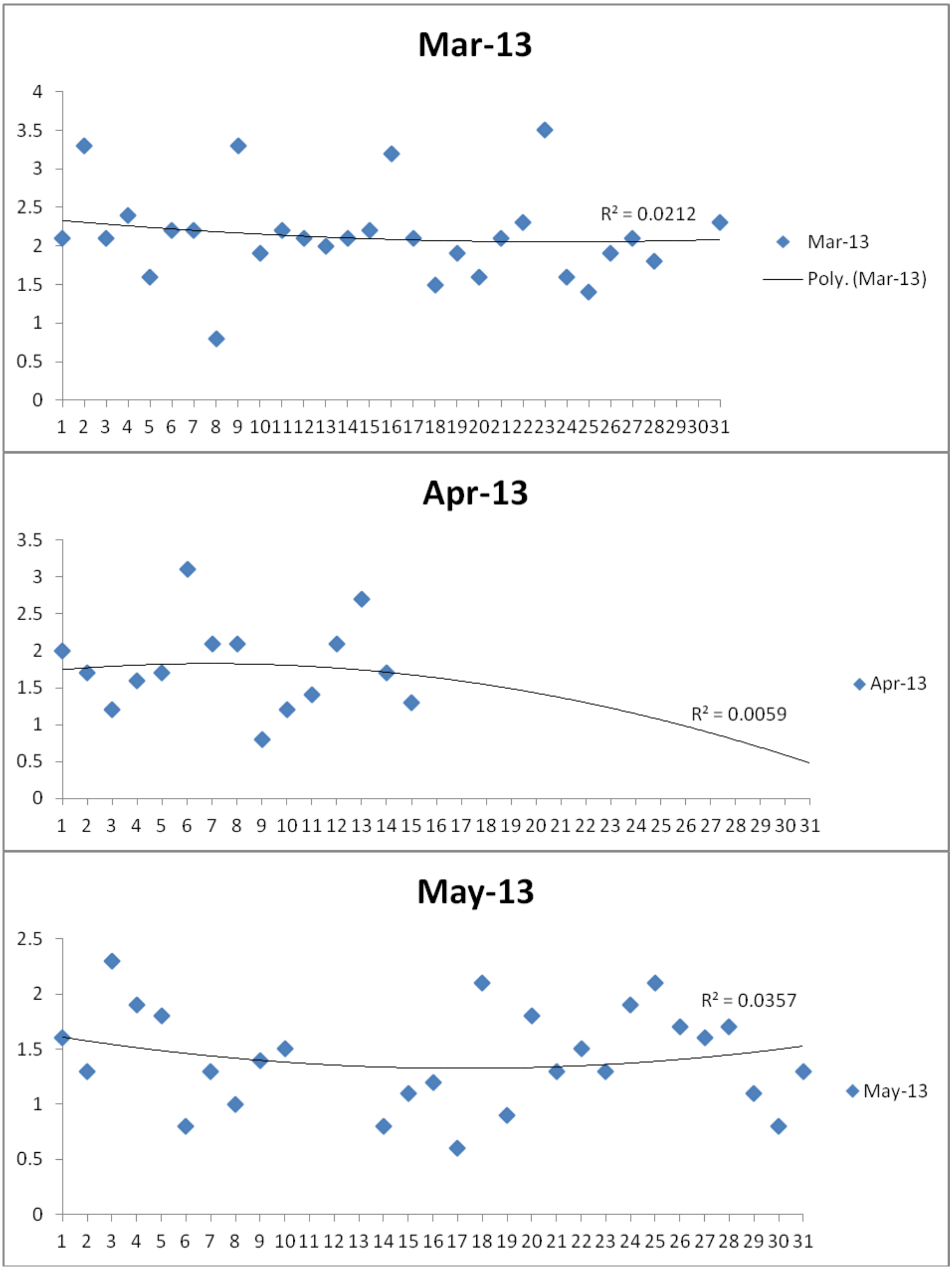

Fig. 4: Scatter plots of daily wind speed from March to May (MAM)

Figures 5 and 6 showed the wind variability in February its corresponding three hourly (180 minutes) moving averages. V_1 represents the morning, V_2 represents the afternoon and V_3 represents the night. The moving average for February had the baselines of the time series lying close to the zero datum line, which is a sign of significant night-time atmospheric stagnation. Average night wind speed for most of those days was observed to be lower than 0.5 ms^{-1}. The higher the base of the sinusoidal time series trend line above the zero datum line, the higher the wind speed for such period, which

implies good atmospheric ventilation. Average night wind speeds for the periods that were significantly raised above the zero datum line for February was about 2.0 ms^{-1}.
February 2013, significant atmospheric stagnation was depicted on days 3 – 6 night-time's recordings with average wind speed of 0.3ms^{-1}, V_1 represent the night time (from 10.00 pm to 6.00 am following day); V_2 is day time (from 6.00 am to 2.00 pm) and noon/evening time (from 2.00 pm to 10.00 pm). A significant occurrence of atmospheric stagnation was observed in the night time readings of February 3, 2013 with an exceptional low average wind speed of 0.143 ms^{-1}. While February 17, 2013 recorded all day normal air ventilation with wind speed of 1.443 ms^{-1}, 1.998 ms^{-1}, 4.482 ms^{-1} for night, day and noon/evening time respectively. This study confirms the recommendation of minimizing the volume of air pollution released into the atmosphere during the night time, as the air can become stagnated and hinder easy dispersion of the pollution from the environment. This is more directed towards the use of electric generating set all night long, especially in densely populated environments. As it has often been reported, most of the disastrous air pollution episodes from the use of electric generators had been over the night and worse still when it is operated in an enclosure.

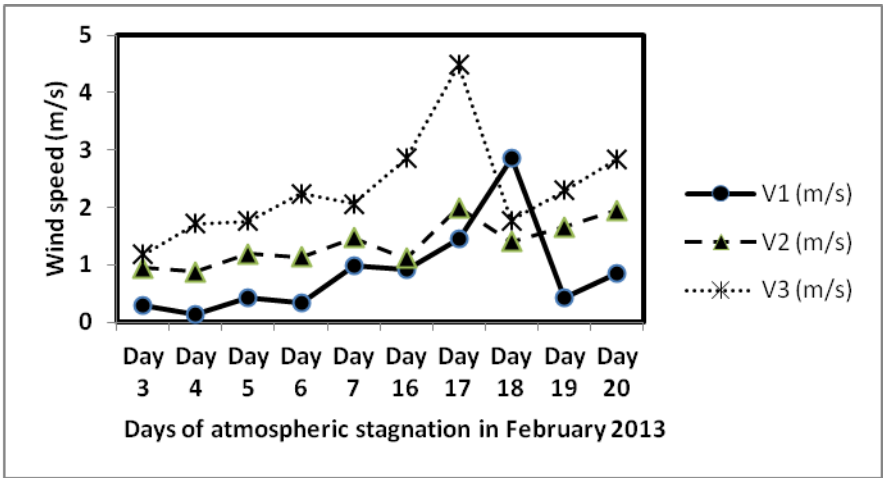

Figure 5: Extracted values for some days showing atmospheric stagnation and ventilation in February 2013

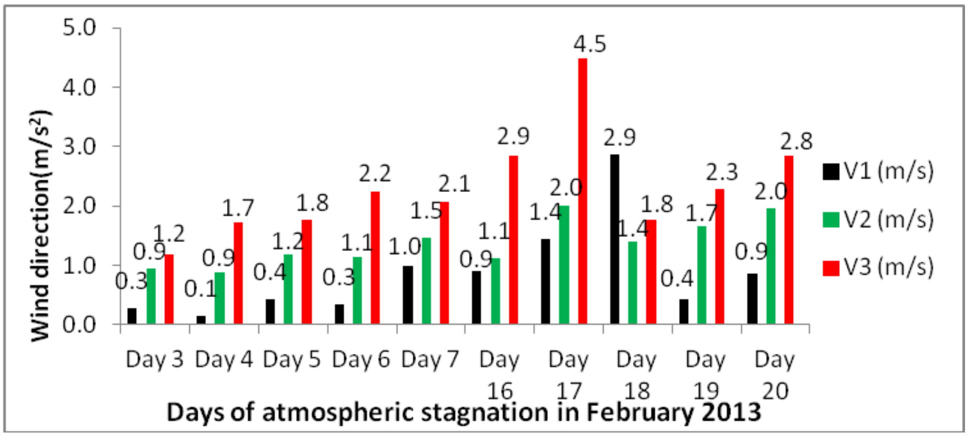

Fig. 6: Variation of wind speed of some days of atmospheric stagnation in February 2013.

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5. CONCLUSION

The use of the Davis weather pro to analyze the wind variability in Ota, Nigeria was successfully investigated. On a macro-scale, wind pattern flows towards the densely populated settlements in December while the wind pattern moves towards the scarcely populated settlements in January and February. A daily wind analysis carried out from December to May, reveals high wind strength in DJF than MAM. The average wind speed for morning, afternoon and night were considered in February. A significant occurrence of atmospheric stagnation was observed in the night time readings of February 3, 2013 with an exceptional low average wind speed of 0.143 ms^{-1}. While February 17, 2013 recorded all day normal air ventilation with wind speed of 1.443 ms^{-1}, 1.998 ms^{-1}, 4.482 ms^{-1} for night, day and noon/evening time respectively. Therefore if a major air borne pollution occurs in Ota, there is an establish pattern which describes regions of worst hit and inactivity.

6. ACKNOWLEDGEMENT

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