

DETERMINATION OF BASIC MEAN HOURLY WIND SPEEDS FOR STRUCTURAL DESIGN IN NAIROBI COUNTRY

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ABSTRACT

Structural Engineers should be able to accurately predict all loads affecting structures. Consideration of wind loads is very important in the structural design especially in the design of high rise structures. This, among accurate prediction of other loads affecting a structure, ensures safe and economic design of structures.

Kenyan structural engineers depend on basic wind speeds which were determined over 30 years ago. It is important to periodically review the wind speeds. This is because the wind speeds experienced could change due to changes in land use like deforestation to give way for infrastructure among other causes.

Most structures are usually designed for a life period of 50 yrs, thus the basic wind speed will have a return period of 50 years.

The objective of this paper is to provide the basic wind speed which will be used to design building structures in Nairobi.

Wind data was taken from 8 meteorological stations within and around Nairobi County. Terrain and altitude correction factors were also determined for all the meteorological stations. These correction factors were multiplied to wind speeds measured at anemometer sites to obtain the design wind speeds for a standard open country terrain and standard elevation.

This data was then analyzed statistically using Gumbel method to determine the basic wind speed, from which wind pressure affecting a typical structure can be calculated.

KEYWORDS: *Basic wind speed, Gumbel method, Terrain Factor, Altitude factor.*

I. INTRODUCTION

Wind loads need to be considered in the design of structures especially high-rise and light weight structures. Wind loads are usually specified as pressure due to the predicted maximum wind velocity. This necessitates accurate prediction of the maximum wind velocity that can be experienced over the design life of structures so that the design is carried out with these wind speeds in mind.

Since structures are generally designed for a design life of 50 yrs, this paper endeavors to give the extreme wind speeds for a 50 year return period in Nairobi County.

Structural Engineers in Kenya use basic wind speeds which were determined about 30 years ago. However it is proper to periodically review the wind speeds to be sure that the loads are still accurate. This is because the changing land use in the city and its environs may result in change in wind speeds which would in turn change the wind loads on structures.

In Kenya, the Kenya Meteorology Department (KMD) is responsible for wind measurements as well as storage of wind data. For purposes of this research, hourly wind speeds for weather stations within Nairobi County and its environs were obtained from KMD. Wind data was obtained for eight weather stations and analyzed to obtain the extreme wind speeds of 50year return period.

II. METHODOLOGY

The general procedure that was followed for analysis of the hourly-mean speeds from each anemometer to derive the design wind speeds was as follows: [1]

Data Quality: The quality of measurements from each anemometer was checked and any inconsistent data separated.

Exposure Correction: Wind records from each anemometer were transposed with respect to the anemometer elevations and terrains around the anemometers so as to be consistent with open country terrain (Engineering Sciences Data Unit (ESDU)) $Z_0 = 0.03\text{m}$

Extreme Value Analysis: Extreme value statistical analysis was carried out.

2.1 Weather Stations

Wind records consisting of hourly mean wind speeds and daily gust speeds were analyzed over a range of five to twelve years.

The anemometer effective height was taken as 10m.

In most meteorological stations wind speeds were measured at 10m height. However in some (mostly the agro meteorological stations), the wind speeds were measured at 2m height and thus they had to be adjusted to 10m heights using the wind profile power law.[3]

The wind profile power law relationship is:

$$u/u_r = (z/z_r)^\alpha \dots\dots\dots(1)$$

Where u is the wind speed (in m/s) at height z (in metres) and u_r is the known wind speed at a reference height z_r . The exponent (α) is an empirically derived coefficient that varies dependent upon the stability of the atmosphere. For neutral stability conditions, α is approximately 1/7 or 0.143.

In order to determine the wind speed at 10m, the relationship was rearranged to:

$$u_x = u_r(10/2)^{0.143} \dots\dots\dots(2)$$

2.2 Exposure Correction

Wind speeds measured by anemometers are affected by other factors other than the strength of winds. The surrounding terrain and elevation of the anemometer site have an effect on the anemometer readings. For instance rough upwind terrains result in slow wind speeds.

To account for the various elevations and terrains surrounding the anemometer, results in wind speeds measured at an anemometer being transposed to a reference terrain at standard height. Transposition allows for comparison of anemometers in close proximity and provides a basis for the comparison of wind speeds.

Wind records were corrected for terrain and altitude. These correction factors were assessed for each anemometer and the factors applied to the wind records to get the design wind speeds.

2.2.1 Terrain Assessments.

Terrain assessments were carried out using the atmospheric boundary layer model used in the ESDU analyses developed by Deaves and Harris. It takes account of varying surface roughness with fetch. [2] Surface roughness length is characterized by a typical z_0 . In this method, the varying terrain roughness with fetch at 300 sectors about the origin is taken account of.

A detailed survey of the terrain roughness was carried out for each anemometer from images obtained from GOOGLE EARTH

The analysis was carried out for each of the twelve sectors of wind direction to a distance of 50 km from the anemometer and for each sector and patch of the terrain, a typical roughness coefficient Z_0 assigned as shown in figure 1.

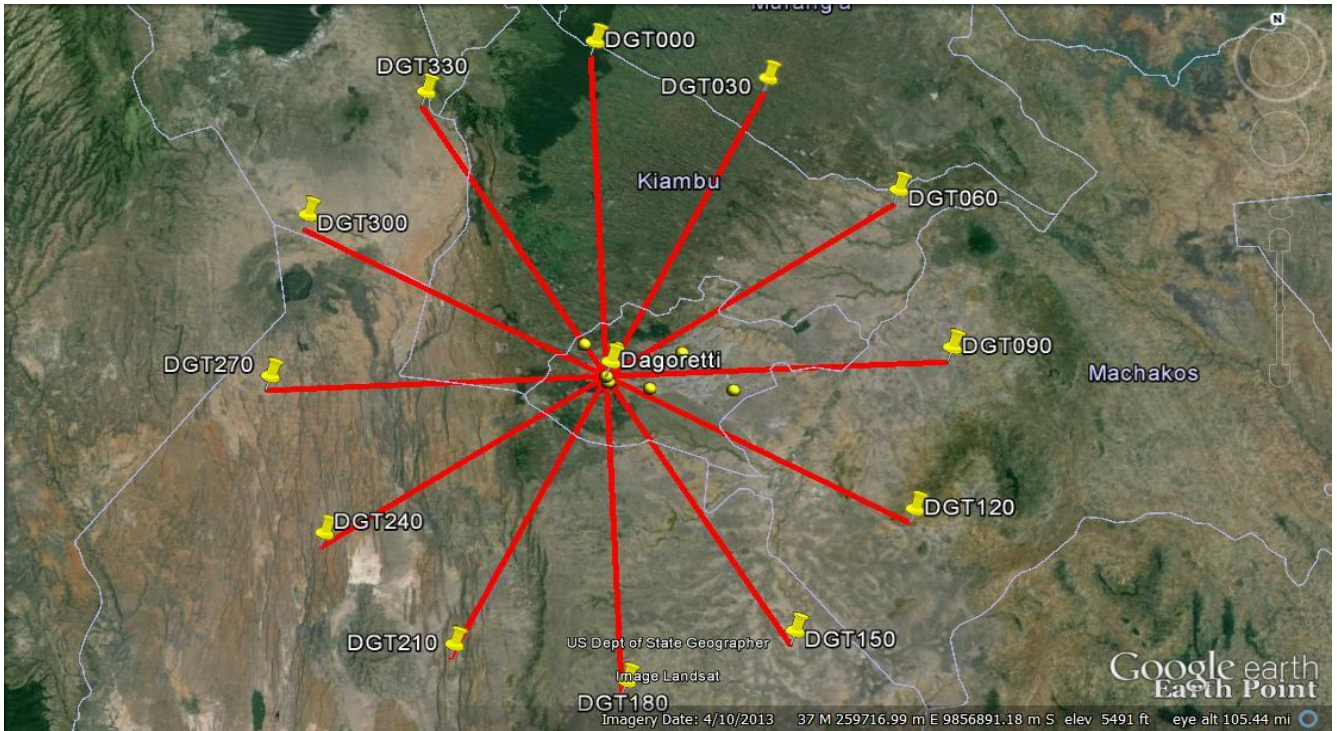


Figure 1. Google Earth Map of Terrain around Dagoretti Meteorological Station.

A conservative estimation was made. This considered a rougher upwind terrain thus resulting in higher factors being applied to the wind records.

2.2.2 Altitude Factor

The design wind speed is usually defined at the mean sea level. Hence, wind speeds measured at anemometers were corrected to account for the effect of the difference in elevation of the anemometer relative to the mean sea level.

Based on these elevations an altitude correction factor was estimated as recommended in international standards, and used in the Eurocode. [2] The altitude factor is of the form:

$$SA = 1 + 0.001(A) \dots \dots \dots (3)$$

Where A is the elevation above sea level in metres.

SA is the Altitude Factor.

These correction factors (both the terrain and altitude factors) were multiplied to wind speeds measured at anemometer sites to obtain the design wind speeds for a standard open country terrain roughness and standard elevation.

2.3 Extreme Value Analysis Procedure

Research has shown that Type 1 Extreme Value Distribution is appropriate for analysis of extreme wind speed measurements in areas which rarely experience hurricanes.[4]

Type 1 distribution is of the form:

$$P_x = \exp[-\exp(-y)] \dots \dots \dots (5)$$

The reduced variate y, is given by:

$$Y = -\ln[-\ln(P_x)] \dots \dots \dots (6)$$

P_x is the probability that an extreme value will be less than a value x within any given year.

2.3.1 Gumbel Method

The following procedure was used to fit recorded Independent Storm Maxima to the Type 1 Extreme Value Distribution:

The Largest wind speed from each storm was extracted.

The series was ranked in order from the smallest to largest.

Each value was assigned a value of non-exceedence according to:

$$P=m/(N+1).....(7)$$

The reduced variate was formed from:

$$R=-\ln(-\ln p).....(8)$$

The Independent Storms Maximum wind speeds were plotted against y, and a line of best fit drawn by means of linear regression, $u=mode=intercept$ of the line, $1/a = slope$ of the line.

For the 50 year return period, the following equation was used to determine extreme wind speed.

$$U_r=u+1/a (\ln R)..... (9).$$

The graphs drawn from the analysis was carried out for the meteorological stations are as shown below:

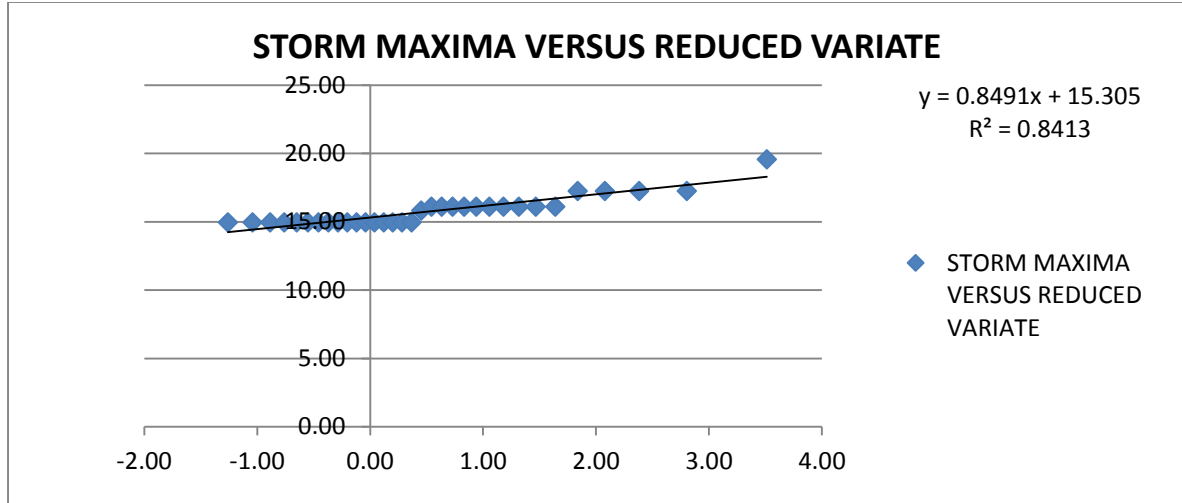


Figure 2: Graph of Storm Maximum Wind Speed Versus Reduced variate of Dagoretti Hourly Wind Speeds.

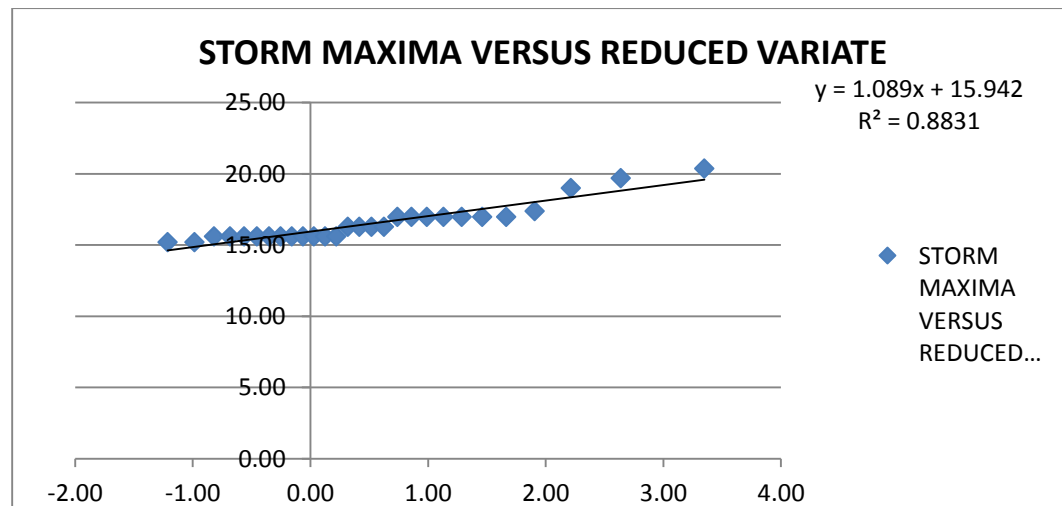


Figure 3: Graph of Storm Maximum Wind Speed Versus Reduced variate of Eastleigh Hourly Wind Speeds.

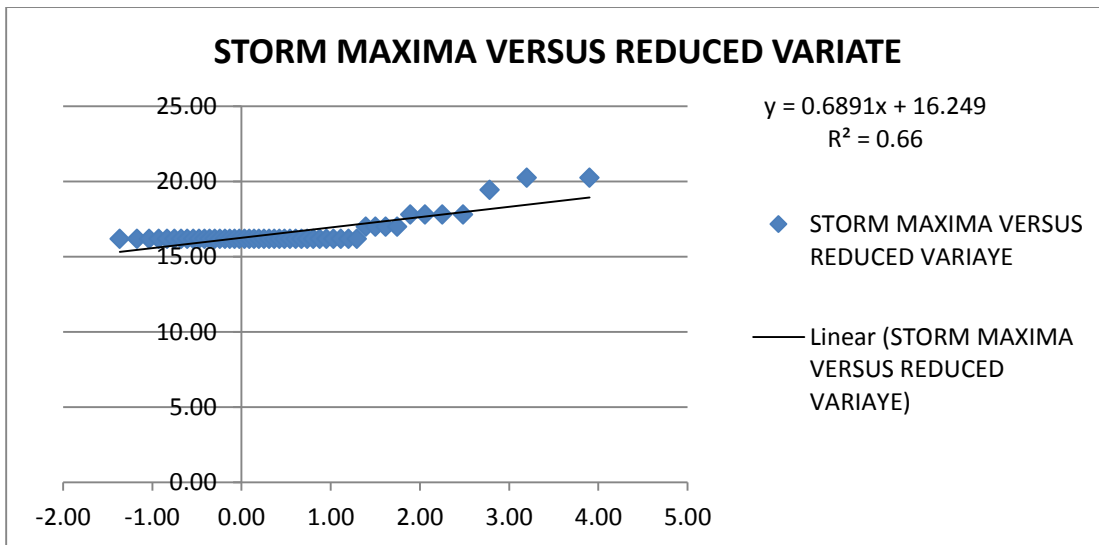


Figure 4: Graph of Storm Maximum Wind Speed Versus Reduced variate of JKIA Hourly Wind Speeds.

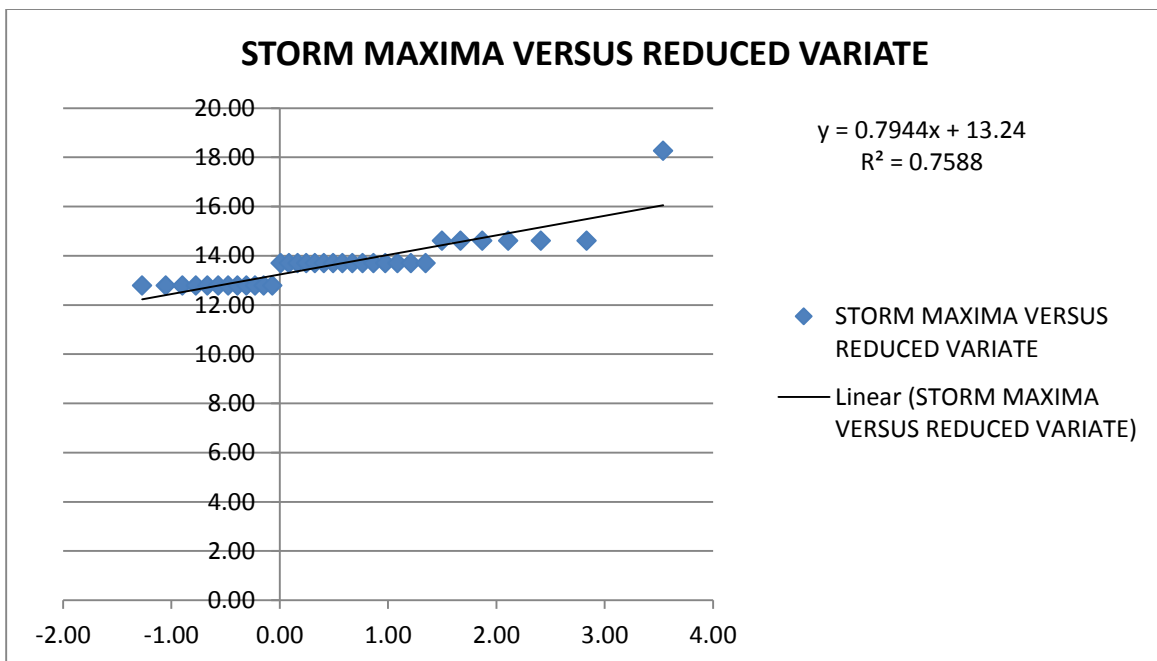


Figure 5: Graph of Storm Maximum Wind Speed Versus Reduced variate of Kabete Hourly Wind Speeds.

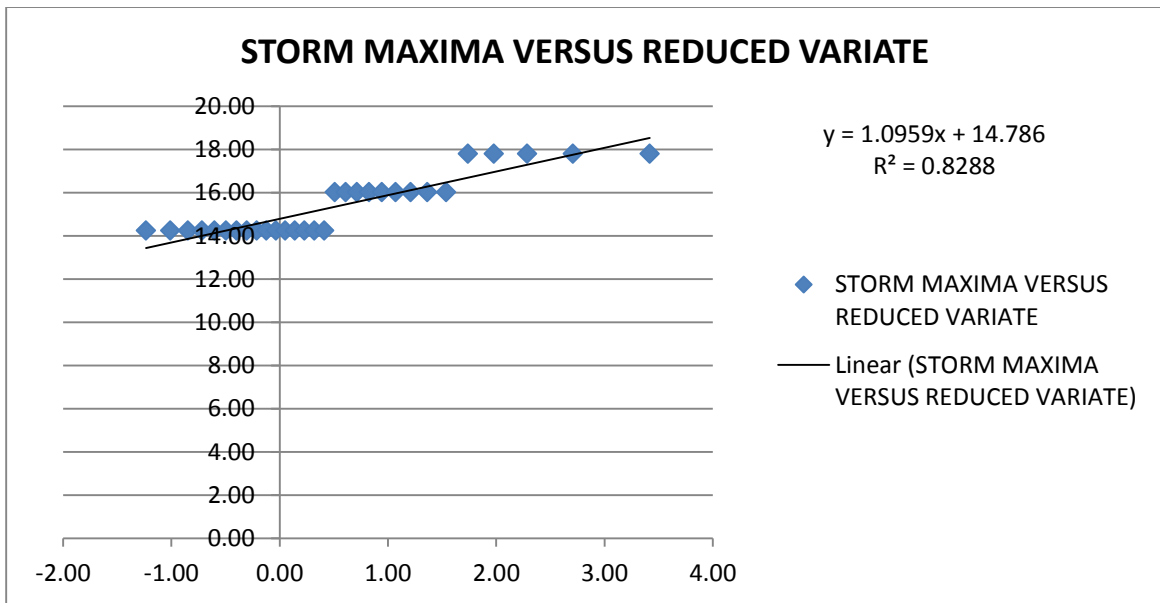


Figure 6: Graph of Storm Maximum Wind Speed Versus Reduced variate of Machakos Hourly Wind Speeds.

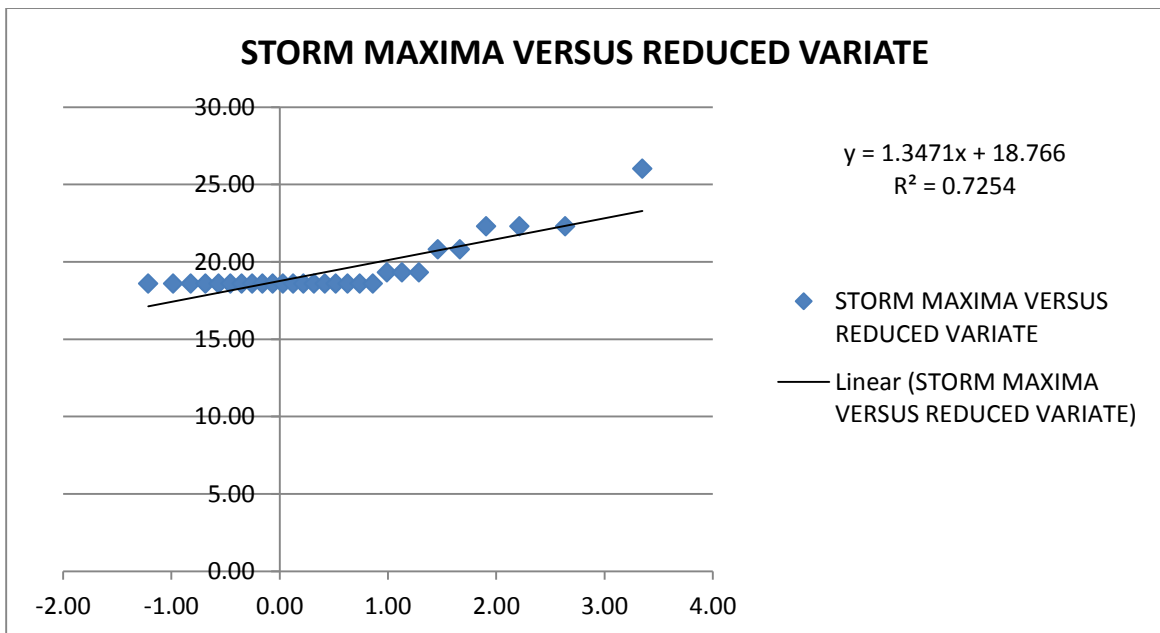


Figure 7: Graph of Storm Maximum Wind Speed Versus Reduced variate of Narok Hourly Wind Speeds.

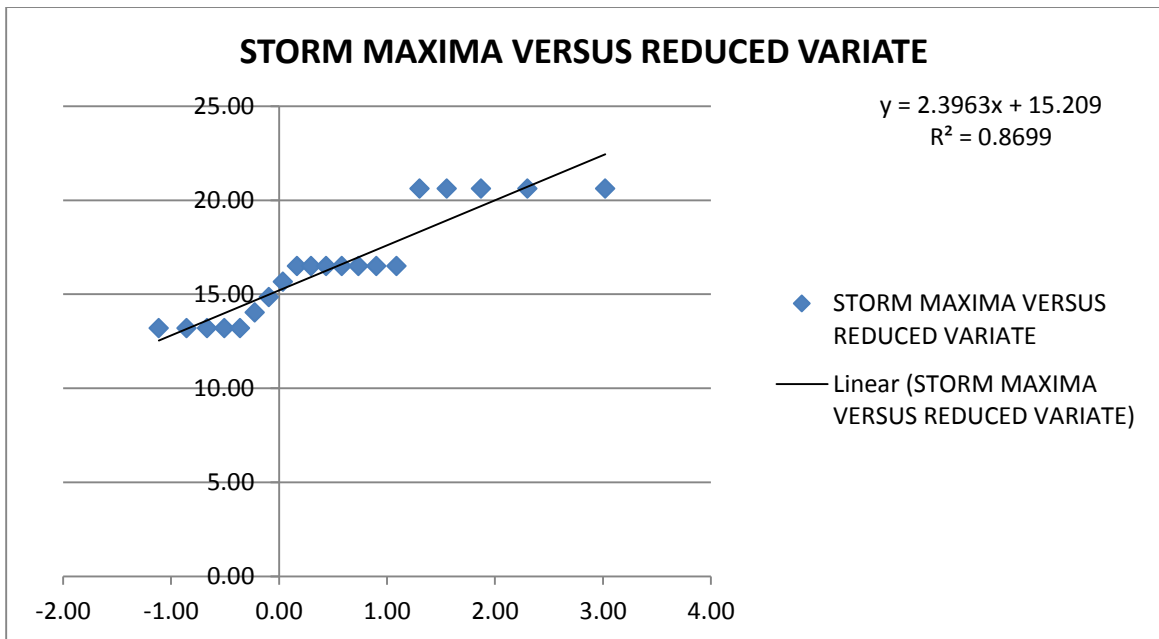


Figure 8: Graph of Storm Maximum Wind Speed Versus Reduced variate of Thika Hourly Wind Speeds.

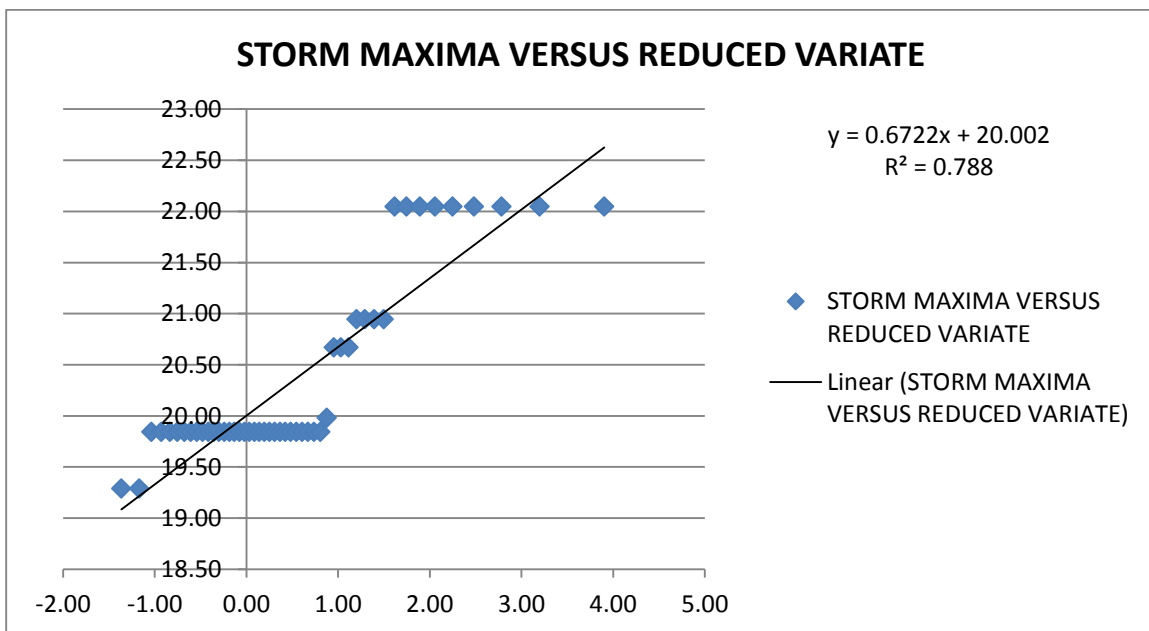


Figure 9: Graph of Storm Maximum Wind Speed Versus Reduced variate of Wilson Hourly Wind Speeds.

III. RESULTS

3.1 Correction Factors

The tables below shows the altitude factors, the terrain factors and the overall correction factors obtained for every meteorological station.

Table 1. Altitude Correction factors for the meteorological stations

ALTITUDE FACTORS								
METEOROLOGICAL STATIONS								
	KABETE	JKIA	WILSON	DAGORETTI	EASTLEIGH	MACHAKOS	THIKA	NAROK
ALTITUDE	1820	1624	1679	1798	1640	1750	1549	1890
FACTORS	2.82	2.62	2.68	2.80	2.64	2.75	2.55	2.89

Table 2. Terrain Correction factors for the meteorological stations

TERRAIN FACTORS												
STATIONS	DIRECTION											
	30	60	90	120	150	180	210	240	270	300	330	360
KABETE	0.5	0.5	0.5	0.8	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
JKIA	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.8	0.8	0.6
WILSON	0.8	0.8	0.4	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5
DAGORETTI	0.5	0.5	0.8	0.4	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
EASTLEIGH	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5
MACHAKOS	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5
THIKA	0.5	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.5	0.5	0.5	0.5
NAROK	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5

Table 3. Combination of Altitude and Terrain Correction factors for the meteorological stations

CORRECTION (ALTITUDE AND TERRAIN) FACTORS												
STATIONS	DIRECTION											
	30	60	90	120	150	180	210	240	270	300	330	360
KABETE	1.41	1.41	1.41	2.26	1.13	1.41	1.41	1.41	1.41	1.41	1.41	1.41
JKIA	1.05	1.05	0.79	0.79	0.79	0.79	0.79	0.79	1.31	2.10	2.10	1.57
WILSON	2.14	2.14	1.07	0.80	0.80	0.80	0.80	1.34	1.34	1.34	1.34	1.34
DAGORETTI	1.40	1.40	2.24	1.12	0.84	1.40	1.40	1.40	1.40	1.40	1.40	1.40
EASTLEIGH	1.32	1.06	1.06	1.06	1.06	1.06	1.32	1.32	1.32	1.32	1.32	1.32
MACHAKOS	1.38	1.38	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	1.38	1.38
THIKA	1.27	1.27	1.27	1.27	1.02	0.76	0.76	0.76	1.27	1.27	1.27	1.27
NAROK	1.45	1.45	1.45	0.87	0.87	0.87	0.87	0.87	0.87	0.87	1.45	1.45

3.2. Wind Speed Equations

The following table shows the equations for the Wind Speeds versus Reduced Variate.

Table 4 Equations of Wind Speeds versus Reduced Variate

STATIONS	EQUATION
KABETE	$0.7944x + 13.24$
JKIA	$0.6891x + 16.249$
WILSON	$0.6722x + 20.002$
DAGORETTI	$0.8419x + 15.305$

EASTLEIGH	$1.089x + 15.942$
MACHAKOS	$1.0959x + 14.786$
THIKA	$2.3963x + 15.209$
NAROK	$1.3471x + 18.766$

3.3. Predicted Basic Wind Speeds

The following wind speeds were recommended after carrying out the analysis:

Table 5 Station Basic Hourly Wind Speeds

STATIONS	Basic Wind Speed(m/s)
KABETE	16.34
JKIA	18.94
WILSON	22.62
DAGORETTI	18.62
EASTLEIGH	20.19
MACHAKOS	19.06
THIKA	24.56
NAROK	24.02

IV. CONCLUSION

The findings here show the basic wind speeds from different meteorological stations in Nairobi County. The time period involved was a maximum of 12 years which is quite short. This was mainly due to lack of data for longer periods and also for other regions within the country. Better and more accurate basic wind speeds can be obtained if more wind speed data is made available.

However, this paper shows the method that should be adopted to determine basic wind speeds for different regions and even for the whole country.

Structural Engineers in Kenya have been using a basic wind speed of 28m/s as the mean hourly wind speed. From the analysis above this is higher than the mean hourly speeds at all the wind speeds within Nairobi County.

However a more comprehensive wind speed analysis using data collected over a longer period e.g. 20 years should be carried out so as to obtain more accurate results.

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