WIND POTENTIAL AND WIND PUMP WATER DISCHARGE FOR DRIP IRRIGATION: A CASE OF LAKE VICTORIA SHORE - KENYA

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A thesis submitted to the Graduate School in partial fulfillment for the award of a Degree of Doctor of Philosophy in Agricultural Engineering of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

DECLARATION

I, Kabok Peter Aguko, declare that this thesis is my original work and has not been presented for a degree in any other university. All sources of information have been acknowledged.

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DEDICATION

This thesis is dedicated to my:

Niece Christine Otieno who through a road accident was taken away from us while she still had her candle on and her hopes that were yet to be fulfilled.

Wife, Petronila Akech Aguko, Children Kay, Sonia, Loice and Ba Joel for constant support and love.

Late father Joel; G Abok; Late brothers; Tobias, Kenneth, Mannasse Tom and my sister in-law Isabel who would have loved to share this achievement with me. And indeed I will not forget my mother the Late Turfena.

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ABSTRACT

Wind Pump drip irrigation is a system that is not documented but developed to link the theory of wind regime, wind machine and drip irrigation to deliver low but frequent applications of water to plant roots for clean energy and to exploit advantages of drip efficiencies. This was by synchronizing wind speed, wind pump discharge, and evapotranspiration. At Lake Victoria Shore (5700 Km^2) Kenya, the challenge was lack of adequate wind speed data obtained only at Ahero, Kadenge, Kibos, Muhuru Bay, Rusinga (2m height) and Kisumu at 2m and 10m heights for the large area. Rusinga had 2m height data and a pre-installed wind pump while Ng'ura site lacked wind speed data but a wind pump was installed. The objective of this study was to determine wind potential and estimate water discharge from variable wind speeds for use of a wind pump drip irrigation system at the Lake Shore. This comprised design and installation of the system at Ng'ura, collection of actual wind speed and discharge data from Rusinga Island. A survey map was used in positioning the pipeline, dug well, water tank and the sedimentation tank at Ng'ura. Field performance of the horizontal axis wind pump coupled to a drip-irrigation system was done at Rusinga Island. A total of 39 test runs was done in a period of 20 days. The actual data from Kisumu and Rusinga were respectively used for the development of percent wind speeds availability and to select the best of the existing instantaneous discharge equations. A fitting statistical distribution (Weibull) model for use with power law index (α) parameter for increase of the wind speeds with height was identified from the Lake Shore (LS) data. It was established that the wind speeds (2m) within the Lake Shore were consistent, fitted the three parameter Weibull distribution and the predicted 10m Kisumu wind speeds from 2m compared well to the actual 10m with an average R^2 of 0.83. The power law index (α) was 0.4 for the Lake Shore, 2 times the actual (0.8) for Kisumu, negatively related to power law index (α) and location. The winds speeds at the Lake Shore showed greater potential nearest to the shoreline with less frequent change of direction. Height of placement of the wind turbine needed to be increased with reference to distance inland and shore line. A Weibull model parameter scale factor (c) for each station was determined and found useful for estimating wind speeds at 10m from 2m using a Weibull model and power law index (α). Particularly, hourly wind speeds for one year for every month was adequate for estimating the wind speeds at a location. The wind speed range percent (WSRP) availability table and the conceptualized model ($Q = K(\sum V_i R_i)$ discharge equation (which compared well to the existing instantaneous wind pump discharge equations) developed is for predicting wind pump discharge and wind strength time limits for irrigation duration. The accuracy of the predicted discharge improves with the length of the hourly wind speed, the startup pump rotation speed and the measuring equipment. Additionally, the wind speeds at 2m height at Ngu'ra were greater than 2m/sec and reasonable for installation of the wind pump. Installation required knowledge of locality/topographical map and Lake Victoria water levels which lost 0.5 m depth at Ngu'ra, estimated to be over 40 m in horizontal distance for data of over 40 years. The Ng'ura reference evapotranspiration (ETo) averaged 4.1 mm based on the LocClime Estimator and compared well with that calculated for Kisumu, Kibos and Kadenge. The wind pump drip irrigation system development and installation approach for Ngu'ra therefore can be used elsewhere along the shore as a guide. It was also established that a direct coupled wind pump to a drip-irrigation system with pressure compensating emitters was technically feasible due to the drip irrigation emission uniformity efficiencies achieved. They were acceptable within standards as they ranged between 93% in the morning to 94% in the afternoon for the 39 test-runs made. Wind regime, wind pump performance characteristics and type of emitter discharge were noted as the critical parameters for the system design. The wind pump drip irrigation as an agricultural production frame work put forward in this study is a basis for exploitation of wind as the green energy. However there is need to enhance data capture in form and format for precision in use of the method as a technology

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	**Meaning**
AC	Alternating Current
ASAL	Arid and Semi-Arid Areas
a.s.l	Above Sea Level
BC	Before Christ
CWR	Crop Water Requirement
DC	Direct Current
ED	Emitter Discharge
EW	Wind Energy
FAO	Food and Agricultural Organization
GC	Ground Cover
Harg	Hargreaves Equation
Hyd	Hydraulic
IL	Irrigation Location
IRD	Irrigation Designer
ITDG	Intermediate Technology Development Group
J	Headloss in Percent of Pipe
K	Constant
KBS	Kenya Bureau Stands
kg	Kilogram
KIE	Kenya Industrial Estate
km	Kilometer
LC	LocClim Estimator
LS	Lake Shore
LVEMP	Lake Victoria Environmental Management Project
m	Meter
S	Second
MF	Manufacturer
mm	Millimeter
N	Number of Observations
NCCK	National Council of Churches of Kenya
pdf	Probability Distribution Function
RP	Production Resources
T	Period Length in Hours
UNIDO	United Nations Industrial Development Organization
UK	United Kingdom
W	Watts

WECs	Wind Energy Conversion Systems
Wh	Watts Hour
WMO	World Meteorological Organization
WP	Wind Pump
WPDI	Wind Pump Drip Irrigation
WPWM	Water-Pumping Windmill
WR	Wind Regime
WSRP	Wind Speed Range Percent

LIST OF SYMBOLS

Symbol	Meaning
α	An Exponent
c	Scale Parameter
ε	Location Parameter
$F(v)$	Cumulative Distribution Function
$f(v)$	Probability density function
ρ	Density
γ_b	Bulk Density of the Soil
k	Shape Parameter
η	Von Karman's Constant
τ	Surface Stress
$u*$	Frictional Velocity
ln	Natural or Naperian Logarithm
V_B	Wind Speed at Height H_B
v	Wind speed
z_o	Surface Roughness Parameter
%	Percent
°C	Temperature in Degree Celsius
ΔH	Head Loss in Pipe
A_p	Plant Irrigated Area
A_t	Total Area of Irrigation within the Interval
C	Pipe Friction Coefficient
C_d	Drag Coefficient
C_L	Lift Coefficient
Cv	Coefficient of Variation
D	Diameter
d_m	Moisture Depletion Allowed or Desired (%)
E_a	Irrigation Efficiency
ET_{crop}	Crop Evapotranspiration
ETo	Reference Evapotranspiration
E_u	Design Emission Uniformity
E_{ua}	Absolute Uniformity as a Percentage
F	Pipe Frictional Factor
F_c	Volume Moisture at Field Capacity (%)
H	Pressure Head of Operation
H_o	Reference Height.
h	Pressure Head
h_B	Height at which the Wind Speed $v_{(B)}$ is Measured

I_h	Irrigation Hours
I_i	Irrigation Interval
IR_g	Maximum Amount or Depth of Water to be Applied
J	Head Loss in Percent of Pipe
K	Constant
K	Constant
K_c	Crop Coefficient
K_r	Non-Beneficial Evaporation which occur in the Conventional Irrigation Methods
K_s	Water Storage Efficiency
L	Length
Lr	Extra Water needed for Leaching
m	Meters
P	Volume of Wetted Soil as a Percentage of the Total Volume
P_e	Pump elevation
P	Power
P_o	Power at Reference Height
Q	Discharge
Q_A	Annual
Q1	1st Season (December to march)
Q2	2nd Season (April to July)
Q3	3rd Season (August to July)
Q_s	System Discharge.
q_{avg}	Average of all the Field Data Emitter Discharge rates
q_d	Design Emitter Discharge
q_e	Emitter Discharge
q_{min}	Minimum Discharge rate
q_x	Average of the Highest one-eighth Emitter Flow rates
R	Water Received by the Plant from other Sources other than Irrigation
r	Radius
R_i	Ratio of the Range Count within the Hour
R_z	Soil Depth or Root Zone to be considered in Meters
S	Second
SD_1	Wind Pump rated Discharge
SD_2	Discharge based on Crop Water Requirement
V_d	Design Wind Speed
V_i	Selected Wind Velocity Average within the Count Range
V_{in}	Initial velocity
V_{out}	Exit Velocity

V_r	Rated Velocity
Wd	Wetted Diameter
Wp	Percentage-Wetted Portion of the Total Soil Volume
V	Wind Speed or Velocity
V_{QT}	Volume of Water Discharged by the Wind Pump
x	Exponent
z	Height at a Point.
z_A	Mean Wind Speeds at Height A
z_B	Mean Wind Speed at Height B

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

The Lake Victoria shore is endowed with vast resources as evidenced in the report of Lake Victoria Environmental Management Project (LVEMP, 2005a and 2003; Odada *et al.*, 2006). Awange and Obiero (2006) assert that "the Lake Shore's main natural resources include; forests, minerals, water, agriculture and wildlife", wind is not considered as a resource. Lack of data on wind for the Lake Victoria shore in Kenya also contributes to this notion and therefore limits its proper assessment, knowledge and utility. It is therefore important to understand the key features of the lake and their role in wind circulation and the wind energy.

Lake Victoria is the reservoir that maintains the basic flow of river Nile. It is the first and second largest freshwater lake in Africa and the world respectively after Lake Superior in the United States of America (Azza, 2006; Awange and Obiero, 2006) and occupies an average area of 68,750 km^2 covering parts of Tanzania (49% of lake area), Uganda (45%) and Kenya (6%). The catchment area of the lake (194,300 km^2) is large and extends to parts of Rwanda and Burundi. The basin is at 1,134 m above sea level and is relatively flat and shallow with a maximum depth of 84 m and a mean depth of 40 m (Rabour *et al.,* 2003; 1998). It is 400 km in the N to S direction and 210 km E to W, with 3500 km of shoreline (UNEP, 2005; Kipkemboi, 2006). It has a number of Islands, with irregular shorelines, shallow bays and gulfs. The Kenyan Lake Victoria gulf is fed by Rivers Sondu, Nyando, Nzoia, Yala and Kuja-Migori apart from the numerous smaller rivers. Generally, direct rainfall and evaporation from the surface of the lake dominate its water budget (Azza, 2006).

The climate of Lake Victoria catchment area is mild with small variations in monthly average air and daily temperature between 15°C and 30°C throughout the year (Romero *et al.,* 2005; Njiru *et al.,* 2006). Rainfall in this catchment area averages 1,300 mm annually, varying from 2,000 mm in highlands to 1,000 mm along the Lakeshore (Aida, 2009). Rainfall exhibits a bimodal pattern with long and short rainy seasons in the period of March to June and October to December, respectively. The physical features which contribute to the wind energy potential within the Lake Victoria catchment include topography, land area, water bodies and settlements.

On the other hand wind speed (has kinetic energy) is the major driving force in wind pump drip irrigation (WPDI) system. Wind energy potential and irrigation are affected by physical features, weather, crop characteristics, soils, water quality, quantity and availability within an area. These factors influence discharge from the wind pump, wind speed and reference evapotranspiration (ET_o). The general overview below looked at these factors with reference to the Kenyan Lake Victoria Shore.

Evapotranspiration rate (ET_o) from grass or alfalfa surface is referred to as the reference evapotranspiration (ET_o). It is the combination of soil evaporation and crop transpiration and is affected by environmental parameters, crop characteristics and management. The ET_o concept at a specific location and time of the year is independent of crop characteristics, management practices and soil factors (Allen *et al.*, 1998).

ET_o is commonly computed from weather data due to the difficulty of obtaining accurate field measurements, as will be for the Lake Shore LS case. Empirical or semi-empirical equations have been developed for use with meteorological data. The FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration (Raes, 2009).

The wind speeds on the other hand must be assessed for wind machines to be installed, which is measured (meteorological records or direct site measurements), estimated or described by suitable local knowledge or statistical distributions such as use of Weibull distribution (Kabok, 2001). Taking on-site measurements for a period of time can be used with the nearest meteorological station to correlate the long-term data to the site. This is necessary in determining the type of a viable wind machine or battery storage capacity in case of electrical generation. Estimation and the statistical distribution analysis are the fundamental approaches in this study of wind speeds for wind energy at the Lake Shore (LS) and even in Kenya today. This is due to the poor status of records and equipment.

Campbell scientific Inc. (1997), states that all agricultural meteorological stations use the 2 meter anemometer as the standard height for estimating water use from crops. World Meteorological Organization, WMO (2006) on the other hand recommends that wind measurements should be taken at a height of 10 meters and above where there are no obstructions. Along the shores of Lake Victoria wind speed measurements are by the 2 meter type cup anemometers (Kabok, 2001). These are used when measuring mean wind speeds between two readings divided by the time interval (daily at LS). This is a challenge for higher height wind energy prediction purposes. Though in WMO (2006), it is stated that 3 years of data obtained gives reasonable averages, knowing that monthly average wind speeds can vary by between 10% – 25% from year to year. This is not appropriate to the LS because of the data available. Other types of anemometers as recorded in Campbell scientific Inc. (1997) show instantaneous meter readings (for example the spinning cups driven either by DC or AC alternators with digital displays). Campbell scientific Inc. (1997) further states that Instruments that measure wind speed instantaneously are not good for finding the average wind speed unless recorded and stored 24 hours a day. Also those anemometers having AC alternators, which measure frequency, are more accurate than those with DC generators.

Today, most instruments with data logger's measure and store wind data and give wind speed instantaneously. They can collect, process, and store average wind speed, elapsed time, pick gust, and wind power density. Some advanced recorders can store the amount of time the wind was calm, which is useful for sizing batteries for stand-alone systems, and the time the winds were above the cut-in speed of a typical wind machine. This is a challenge in the Kenyan gulf and most of the developing countries due to lack of appropriate instruments.

A windmill comprises of an installed rotor on tripod tower, its base and a reciprocating water pump. The discharge performance from a wind pump is estimated through performance curves and tables developed by manufacturers. For instance Table A1.1 in the appendix indicates the average daily output at different pumping heads and average speeds designated as "light" 2-3m/s, "medium" 3-4m/s and "strong" 4-5m/s (Bob Harries Engineering Ltd [BHEL], 2008). Fraenkel (1986) asserts that the manufacturers' performance curves and tables are often made to be impressive but are inaccurate, unreliable or even incomplete in data. Although, at times low performance occurs due to inapplicable pump size or stroke, which when changed can result into an improved performance.

To irrigate a crop by a wind pump; the discharge on wind speed availability with time of the day, week, and month or season should be calculated. The estimate of wind pump performance combines data of hourly average wind speeds with wind velocity distribution histogram or the number of hours in the month that the wind blows within predefined speed (Fraenkel, 1986). In other words the output of a wind pump in various wind speeds is multiplied by the statistical average number of hours that the wind blows within each speed range (or speed "bin" output per hour at that speed and the number of hours speed recurs). Use of annual average wind speeds needs a margin of safety in the calculations (depending on use of water). The sum of all bin outputs gives the total annual output for water use.

This output can also be achieved graphically by using the velocity frequency distribution of the wind regime and multiplying by the windmill performance characteristic to obtain the energy output as is illustrated in Fig B1.1 in the appendix. The curve and the tables approach when used are unreliable because the method is as good as the wind and performance data available. A simple rule of thumb when adopted for cross check, assumes that a wind pump system, on average, is 17% efficient in converting wind energy into hydraulic output (Brown, 2006), as given by equations 1.1. This in many cases gives a good estimate of the losses in a wind pump system and the total efficiency.

$$P = 0.1V^3\ {}^{W}\!/_{m^2} \quad \text{..}(1.1)$$

where; P = Power (kW), V = Wind Speed (m/s).

The predicted output by equation (1.1); rule of thumb is in the range of 0.6 to 1.6 greater by use of the constant 0.1 and mean wind speeds. The sum of the efficiency factors vary from 7 to 27% of the value converted to hydraulic energy (shaft, shaft - pump, pump, and actual wind energy to wind energy). The 17% overall efficiency used in arriving at $0.1V^3$ rule of thumb would hence vary with different wind pumps and wind regimes by plus or minus 10%.

1.2 Statement of the Problem

Lake Victoria has resources that are being exploited for the benefit of the people around it. Among them are fisheries, agricultural activities and transportation. Wind energy is not fully exploited due to lack of awareness coupled with limited data on its distribution and potential. Therefore, there were gaps that required a study on its viability for application in irrigation. This should include relationship of the temporal and spatial variations of wind speed to discharge for crop water needs. A conceptual framework that synchronizes the wind speeds conversion systems to discharge and drip irrigation (parameters/governing equations) is considered a new phenomenon that was proposed/investigated to solve the challenges of water use efficiency and the WPDI farming technology need. The demand for irrigation is due to change in climate and seasonality and need for food security.

In the present data, the Weibull equation has been applied for Kisumu and the available Lake Shore stations at 2m height and generalized for wind speeds for the entire Lake Shore. This was because of need for a method (statistical distribution or otherwise) that enables the prediction of wind speeds from 2m to 10m (the expected windmills height) which is applicable for the entire lake shore. The other contributing factors to this were varying effects of vegetation, terrain, and settlements and data inadequacy. Essentially there was no relationship for predicting wind pump discharges from varying wind speeds. Neither the field performance of a wind pump drip-irrigation which is not documented for the Lake Shore.

1.3 Objectives

The broad objective of this study was to determine wind potential and estimate water discharge from variable wind speeds for use of a wind pump drip irrigation system at the Lake Victoria shore–Kenya.

The specific objectives are:

1) To determine wind speed variations at the shore of Lake Victoria, Kenya.
2) To develop a relationship for predicting wind pump discharges from hourly/varying wind speeds.
3) To evaluate the field performance of a wind pump drip-irrigation system.

1.4 Research Questions

1 How are the wind speed variations at the Lake Victoria shore in Kenya?
2 Is there a suitable relationship that can be developed between wind pump discharges and hourly wind speeds?
3 What are the precedent aspects, installation parameters and performance efficiencies for a wind pump drip-irrigation system at the Lake Victoria shore?

1.5 Justification

Wind is an important green energy resource in the world today as well as drip irrigation technology which has advantage of economic use of water, labour, and significant in sustainable socio-economic and ecological development. It is noted that wind data availability is critical in making decisions on the installation of the wind pump irrigation systems. However, the Lake Victoria shore in Kenya has inadequate meteorological stations suitable for estimating wind speeds for determining energy and water discharge for irrigation.

At the Lake Victoria shore wind speed data is measured at 2m height except for the Kisumu station while wind mills are installed at a minimum/referenced height of 10m or higher. Hence, the daily wind speed measurements are inappropriate for determining discharges for calculation of irrigation depth and duration for wind pump drip irrigation (WPDI) system. Therefore, it is necessary to determine wind speeds, their time interval, discharge and Reference evapotranspiration ET_0 for the installation and use of the WPDI system. The available data was inadequate in duration, time interval and form. It was also captured with inappropriate equipment to enable analysis of the WPDI system. The daily measurement as practiced in Kenya depicts a large variation of wind speeds when averaged .These imposed the need for estimation of wind speed and discharge, by use of existing data and knowledge.

Discharge component of wind pump drip irrigation system is important for decision on both irrigation area and interval. Therefore there is need for use of governing equations that relates wind speeds and discharge, irrigation area and depth in WPDI system. Aspects such as water availability (quantity and quality), suitable topography, and parameters related to soil and crop need to be estimated or adopted and tested for installation of WPDI technology.

This research seeks to utilize wind energy, wind pump and drip irrigation in an area where both wind data and the relevant parameters (Wind pump discharge relationship, Wind speed duration, ET_0) for the system are limited. It also fills the knowledge gap and brings into focus the scientific theory for preparation and installation of a wind pump drip irrigation system. Although the study focuses on the gulf on Lake Victoria Kenya, the findings of this study are applicable to similar type of environment and also where adequate data are available.

Due to lack of modernized and adequate meteorological recording equipment data availability at the Lake shore will still be a challenge even in future. Hence, methodology and approaches for prediction or estimations needed to be improved through further research for the benefit of agriculture or in using wind mills as one of the green energy technologies.

Already it's ascertained by Kabok (2001) that the limiting aspects to drip irrigation system are wind pump, wind regime, area to be irrigated and other irrigation parameters These factors would definitely affect any other irrigation method when using a wind pump. It is therefore intended that an adaptive training/monitoring be done to this system together with the technicians and farmers.

This should be to ascertain the technical options and later gather and consider the economic viability of the options.

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APPENDIX

Table:A1.1: Amount of Water Delivered per Day (m^3) by Kijito Wind Pump Models

Model	3.65 m			4.88m			6.10m			7.32m			7.92m		
Wind (m/s)	Light 2-3	Med 3-4	Strong 4-5	Light 2-3	Med 3-4	Strong 4-5	Light 2-3	Med 3-4	Strong 4-5	Light 2-3	Med 3-4	Strong 4-5	Light 2-3	Med 3-4	Strong 4-5
Head (m)															
[illegible]	10	28	59	21	71	150	39	107	227	61	167	354	70	192	407
[illegible]	5	14	29	10	35	75	19	53	113	30	83	177	35	95	204
[illegible]			15	5	18	37	10	27	57	15	42	89	17	48	102
[illegible]		7	11	4	14	28	7	20	43	11	31	66	13	36	76
[illegible]		5	7	3	9	19	5	13	28	8	21	44	9	24	51
[illegible]		3	6		7	16	4	10	24	7	18	36	8	21	41
[illegible]		2	5		6	12	3	9	19	5	14	29	6	16	33
[illegible]			4		4	9		7	14	4	10	22	5	13	28

Source: BHEL; 2008

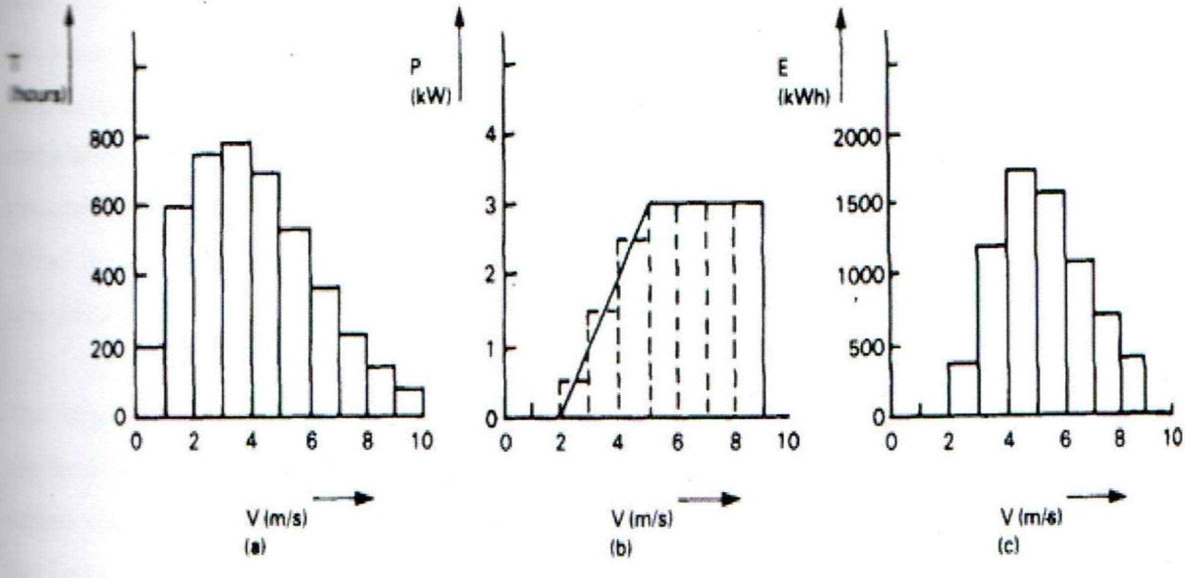

Fig:B1.1: **Wind Mill Output Fraenkel (1986)**

CHAPTER TWO

LITERATURE REVIEW

2.1 Wind Pumps

2.1.1 Wind

Global air circulation (wind) across the surface of the Earth is caused by convective currents that originate from sun's rays; solar radiation heats the earth's surface and the surrounding air. The warm air rises to the atmosphere and the cool air returns to the Earth surface (Edelstein *et al.,* 2006). This cycle is continuous and air in motion is described as the wind WMO (1981).

Many studies have been done to document types of wind on the earth's surface which includes the general atmospheric circulations that occur above the atmospheric boundary layer (ABL), the transition zone between the surface and the free atmosphere, Schneider (2006); Talley (2010). Notably, a British scientist George Hardley in 1735 suggested that there is wind circulation between the equator and the tropics (Hardley circulation) where Kenya is located. This phenomenon is caused by higher temperatures between the equator and the lower temperatures in the northern and southern hemispheres which are 30° N and 30° S respectively. The other forms are the subtropical jet streams due to coriolis force, monsoon circulation due to trade winds, tropical cyclones (tropical disturbances), and the Rossby circulation due to the wavy westerlies in the southern or northern hemisphere (American Wind Society [AWS] scientific, INC. CESTM., 2009). Large water bodies and landforms also play a role in the atmospheric movements.

The large-scale weather systems and wind patterns therefore form the framework upon which the local factors such as topography, vegetation cover and type of settlements influence the actual wind conditions in an area or local circulation as a source of wind energy. The case of the Lake Victoria Shore can be taken as local circulation. The factors that influence the air flow in the area are: turbulence (eddies), nature of the underlying surface roughness (wind shear), heating and cooling (breezes), topographic features, nearby forests, buildings, rainfall, Lake to land (breezes), thermal changes; heating or cooling gradients due to location and time on the earth's surface. Another factor is the mountain valley circulation due to hill ranges near the lake. These circulations arise because the solar radiation heats the hill or valley slopes differently and thereby creating pressure differences;

The Lake Victoria (68,750km^2) with her characteristics (Table 2.1a) experiences sea breeze systems which are dominant over other general circulations throughout the year (Flohn, 1966). The general flow is southerly during northern summer and northerly during northern winters. This is within the view of the atmospheric circulation normally described as plenary or prevailing, local winds or local general circulation for their dominant and relatively constant characteristics that are observable (Van Vilstren, 1980, Hankins, 1989).

Table:2.1a: Lake Victoria Surface Area, Shoreline and Basin Area per Country

Country	Lake Surface Area		Shoreline		Catchment area	Basin
	Km^2	**%**	**Km**	**%**	**Km^2**	**%**
Kenya	4,113	6	550	17	38,913	21.5
Tanzania	33,756	49	1,150	33	79,570	44
Uganda	31,001	45	1,750	50	28,857	15.9
Rwanda	0	0	0	0	20,550	11.4
Burundi	0	0	0	0	13,060	7.2
Total	**68,870**	**100**	**3,450**	**100**	**180,950**	**100**

(**Source**: SIDA, 2004)

Table:2.1b: Lake Victoria Characteristics

Character	Units
Volume	2,760 km^3
Mean depth	40 m
Maximum depth	84 m
Maximum length	400 km
Maximum width	212 km
Mean width	174 km
Shoreline	3,440 km
Flushing time	140 yrs
Refill time/residence time)	23 yrs
Annual lake level fluctuations	0.01 – 1.663 m

(**Source**: Crul,1998)

2.1.2 Energy in Wind

Wind energy is a product of air movement surrounding the earth up to approximately 64 km in altitude. It has been used by many civilizations dating back to the 18th century industrial revolution for power generation, (Ragheb, 2008). This technology is available in many parts of the world and has evolved as in Table 2.2. WMO (1981) provides historical evidence of the use of wind energy along the River Nile, China, Persia and the Middle East region, some centuries Before Christ (BC). Later it spread throughout the Mediterranean and was introduced in Europe in the 11th Century. The Dutch later improved its use and by the beginning of 20th century, steam and combustion engines gradually replaced the wind machines but their presence has remained in the rural areas (Cutler, 2007).

Wind energy has been modified many times to challenge the conventional sources as one of the renewable energy sources which is used to pump water, grind grain and to generate electricity among other uses.

Table:2.2: Historical Development of Wind Energy Conversion Systems

Period	Machine	Application
640AD	Persian Wind mills	Grinding
Before 1200AD	Chinese type Sail wind mills	Grinding, Water Pumping
12th Century AD	Dutch Wind Mills	Grinding, Water Pumping
1700 AD	Dutch Wind Mills to America	
1850 to 1930 AD	American Multi-blade	Water pumping. 35 VDC power
1888 AD	Brush Wind Turbine; Dia 17m, Tower, 18.3 m	12 kw Electric Power
1925 AD	Jacob's three blade Propeller, Dia, 5m, 10 -20 m/h,125 to 225 rpm	0.8 to 2.5 KW at 32VDC
1925 AD	Savonius Machine	Mechanical or Electrical Power
1931 AD	Yalta Propeller, Russia; 2 blade, dia, 33m	100 KW
1931 AD	Darrius Machine	Electrical Power
1941 AD	Smith -Putnan Propeller, 2 bladed, dia 58m, 30 m/h, 28 rpm	1250 KW
1980's AD	2 bladed Propeller (commercially Available)	225 KW
2000 AD	HAWT, VAWT	400 -625 kW, 1.2 t0 3.2 MW

(**Source:** Kedare, 2002)

where; HAWT is horizontal axis wind turbine, VAWT is vertical axis wind turbine and VDC volts direct current. AD is Anno Dominni (year of our Lord-number of years after Christ) KW is kilowatt

In a flowing mass of air (wind), the kinetic energy is given by $\frac{1}{2}mv^2$ where m = mass of air (kg), V = Velocity of air (m/s) (Yao *et al.*, 2011). The instantaneous energy available is given by P (kinetic) $=\frac{1}{2}\rho A v^3$ = ½ (ρv^2A) v where P= power and A= area, ρ= is air density and v is the wind speed/velocity. The factors that affect the wind characteristics also affect power in WPDI system, for example power variation with height as is given in equation 2.1 below.

$$\mathrm{P}/\mathrm{P_0} = \left(\frac{\mathrm{H}}{\mathrm{H_0}}\right)^{3\alpha} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

where P is power at a certain height (H), P_o is power at reference height (H_o) and α is an exponent index.

The wind rotor extracts wind energy as it slows it down, too much slow-down means the air stream may flow around the rotor. A balance must therefore be reached and the maximum power is extracted when the wind velocity in the wake is one third of the undisturbed wind stream (De Jongh and Rijs, 2004; Horia, 2009). The theoretical maximum fraction extracted power is $^{16}/_{27}$ or 59.3%, called Betz limit in honour of Carl Betz (1926) who derived the value, given by:

$$P_{max} = \frac{1}{2}\left(\rho A \frac{2}{3} V\infty\right) V^2\infty = \frac{1}{2}\left(\rho A \frac{2}{3} V\infty\right)\left(\frac{1}{3} V\infty\right)^2 \text{ or}$$

$$P_{max} = \frac{16}{27}\frac{1}{2}\rho A V^3\infty \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

In practice the fraction achievable is less than 40% because the efficiency of the WEC's (rotor) is reduced by fluctuations in wind and wind direction (Ragheb, 2011).

The effects have been developed into a rule of thumb for a first estimate of the output of water pumping wind mill (WPWM), wind to water at a location with average wind speed (V) as:

$$P_{water} = 0.1AV^3(w) or$$

$$q = \frac{0.1V^3}{\rho g H} \quad \text{.......} \quad (2.3)$$

By use of the relation P =QρgH (W), where ρ= 1000 kg/m^3 g = gravitational force Q-=discharge and H is the head. Equation 2.3 formed the basis of the derivation and use of the instantaneous discharge equations.

Wind speeds vary with height and increase away from the Earth's surface due to less friction caused by turbulence over and around obstructions such as buildings, mountains, and trees. Wind machines therefore are placed on towers so that the rotor's bottom edges are at least 10 meters above and 100 meters away from any obstruction (Sagrillo, 2005). The use of a larger tower helps in overcoming the effect of surface roughness. Power in a wind machine, however is directly proportional to the wind speed and air density. The change in density of the air, decreases with altitude (Table 2.3) and varies from season to season by between10% to 15%. Lake Victoria basin is at 1,134 m above sea level with a maximum depth of 84 m and a mean depth of 40 m (Holli Riebeek, 2006).The altitude affects wind power output as wind speeds are reduced by about 10% for every 1,000 meters above sea level (Fraenkel, 1986; Christina *et al.*, 2009; Benjamin *et al.*, 2010).

As opposed to changes in air density, changes in the swept area of the rotor significantly change the power. Doubling of the rotor area doubles the wind power. Since the power output of a wind machine is proportional to the cube of the wind speed, power increases eight times when wind speed is doubled (Argaw *et al.,* 2003).

Table:2.3: Variation of Air Density with Altitude above Sea Level

Altitude (m)	0	152	305	610	915	1524	1829	2134	2439	2744	3049
Correction factor	1	0.99	0.97	0.9	0.9	0.85	0.82	0.79	0.76	0.73	0.7

Source; Argaw *et al.,* (2003)

The air density correction factor for Lake Victoria can thus be estimated from the determined altitude of 1134 as 0.87.

2.1.3 Wind Energy Conversion Systems (WECs)

Wind energy conversion systems (WECs) are wind machines which convert wind energy (input) to work (output) (Van Vilstren 1980; Hankins 1989; Kedare 2002; De Jongh and Rijs 2004). They are made of common components namely the rotor, shaft, gear or crank mechanism, towers (tripod or guy wires), steering and storm protection mechanisms (vanes). Distinction has been made between large (WECs >100 kW) and small ($SWEC_S$ < 100 kW) also referred to as wind turbines or wind pumps. The orientation of the rotors further distinguishes them as vertical axis or horizontal axis WECs. The vertical axis WECs have the shafts in the vertical plane and the blades sweep in the horizontal plane, while the horizontal axis WECs have the shaft in the horizontal plane and the blades sweep in the vertical plane; and can be upwind with tail vane or downwind without tail vane (Barakati, 2011). Examples of horizontal axis WECs are: the multi-blade water pumping windmill, the upwind three blade rotor and the downwind four blade rotor. Examples of vertical WECs are: (a) Darrieus (b) Savonius and Cyclotube. The vertical WECs accept wind in any direction and are regarded as not very efficient (Yao *et al.,* 2011). The WECs can be used for other purposes such as powering compressors (Synman, 1980).

In Kenya, the Global Wind Pump Evaluation Programme (It Power Ltd, 1987; Kruger Consult, 1993) summarizes the development of WECs. The white settlers introduced them at the beginning of the 20th Century using mainly: the Climax, Southern Cross, Comet, Dempster, and Aero motor Machines. Their use was mainly concentrated around Nanyuki, Eldoret, Kitale, parts of the Rift Valley and along the Coastal region of Kenya. They were imported until the seventies when significant efforts were made to design, develop and commercially manufacture them locally.

The developers included UNIDO/KIE Project along the Lake Victoria shore (Kenya), Pwani fabricators along the Coastal region, University of Nairobi Research/NCCK Project, Mbita Mission along the Shore of Lake Victoria, Kijito Wind Pumps (Thika), in co-operation with ITDG of the United Kingdom, Salvation Army (Thika) and Homa Hills Centre based along the shore of Lake Victoria. Today Kijito and Pwani fabricators are still operational and are manufacturing specific wind pump designs for use in Kenya and other regions in Africa. More recently, Bob Harries Engineering Ltd. has been involved in the development of a range of small Wind pumps called the Kijito "2000" Series (Mike, 2002). In this study the horizontal axis water pumping windmill is used for drip irrigation because of its availability.

2.2 Wind Variation with Height

2.2.1 Wind Characteristics

The interest on wind characterization studies emanated from the extractable power potential for the needs of man. The characterization of the operation of the WPDI is not an exception and is to be done with respect to the day spectrum of a wind speed interval. This is linked to the capability of WPWM in transformation of wind to discharge and to irrigation characteristics. Though, much of the characterization efforts have been limited to the electric turbines. Statistical characteristics of boundary layer wind speeds have been the subject for many researchers. Hennessey (1977) mentions Planck's distribution, bi-variate and tri-variate normal distributions. The statistical distributions tested and which have been put to use are: Rayleigh, Pearson type III, 2 & 3 parameter log normal, log Pearson type III, normal distribution, and the 2 & 3 parameter Weibull distributions Lima and Celso (2012), reported on wind characterization by graphical and the statistical methods. The details of the distributions are best found in standard statistical texts. The applications have been in the fields of agriculture, communication and energy.

The 2 and 3 parameter Weibull distribution have been recommended as practical and fits both the upper air and the surface wind speed (Hennessey, 1977). Its use in wind speed, wind energy and especially its parameter estimation are given by Takle and Brown (1977); Stewart and Essen (1978); Justus *et al.,* (1978); Van Der-Auwera *et al.,* (1980); De Jongh and Rijs (2004).

Particularly, the two-parameter Weibull distribution has been applied by various researchers, among them; Altaii and Farrugia (2003), Al-Nassar *et al.,* 2005. Jaramillo and Borja (2004) indicated that it must not be generalized for all cases as they found out at La Ventosa in Mexico that a mathematical formulation by the bimodal Weibull and Weibull probability distribution function (pdf) represented better the wind speed frequency distribution of the area and could be applied in other areas where this characteristic is exhibited. The other methods include: - graphical representation of f(x) and F(x) (least square fit to observed distribution), standard deviation analysis (method of maximum likelihood/moments) and energy pattern analysis.

The existing long records of synoptic or agricultural weather stations and sometimes through short period measurements at the site, assists in the preliminary wind site assessment. The equipment listed in Bailey *et al.,* (1997) for assessment include: (i) Hand held anemometers for instantaneous wind speeds and they are limited in wind power data assessment (ii) Wind run-odometers which are cupped rotors connected to an odometer and record distance in kilometers as wind passes the instrument, (iii) Recording anemometers-they record wind speeds by time in digital form or microprocessors or using strip charts or tapes. Daily or weekly averages are recorded depending on the instrument. Today, as is reported by AWS Scientific Inc. CESTM (2009), there are more advanced methods of wind speed measurement. These record actual wind distribution and there may be no need for reliance on the statistical models. The earlier form of wind speed estimates relied on the Griggs - Putman index for interpretation of the degree of flagging of particular vegetation for remote forested areas (WMO, 1981; De Jongh and Rijs, 2004).

2.2.2 Wind variation with height.

The height of operation of water pumping windmill is of interest because it will determine the amount of energy received/ harnessed by a WPDI system since higher heights means higher wind speeds/energy. The surface layer of the wind is not always constant. The height and depth may vary from place to place because it's the constant momentum flux area. All of the wind data measuring heights within the Lake Shore are at 2m height except for Kisumu with additional 10m data and hence any prior to installation of a Water Pumping Wind Mill (WPWM), the 2m height data would be used for the preliminary estimates. Knowledge of the applicable wind speed distribution models for estimating increase of wind speed with height for the area is therefore a prerequisite for use and prediction of the performance of WPDI within the Lake Shore today.

Always, Airflow close to the surface is often turbulent (irregular, diffusive, dissipative among others) than being laminar. Laminar flow may only be experienced in an aerodynamic smooth surface for example, calm sea or in situations when irregular motions are effectively handled by the work they do against stable density stratifications. Hsu (2003) and WMO (1981) reported that in an atmosphere where temperature decreases nearly by 10°C km^{-1} upward, the mean wind profile becomes logarithmic. The case of the lakeshore atmospheric stability is unknown for the operation of a wind pump.

Carruthers (1943), WMO (1981), Panofsky and Dutton (1984), Dennis (1997) and Yahaya and Frangi (2009) have details of the characteristics of turbulence including them being three dimensional, variable with vertical temperature stratification and fluctuations (eddies). The turbulence may be highest close to ground surface and exhibit constant characteristics above certain heights. Eddies transport momentum from one level to another, while the ground level (or the height where wind speed become zero) determines the roughness height (Z_o) as suggested in Hsu (2003); Maeda *et al.,* (2003); De Jongh and Rijs (2004).

Estimates of the energy or discharge potential of the WPWM for the height of operation within the lakeshore will therefore borrow the logarithmic and the power laws; which are commonly used in estimating wind speeds at heights other than measurement height. Similar studies have been conducted by Sultan (1943), Monin and Obukhov (1954), Panofsky *et al.,* (1960), Pasquill (1968) and WMO (1984) among others. Hsu (2003), Altaii and Farrugia (2003), Jaramillo and Borja (2004), AI-Nassar *et al.,* (2005) have successfully applied the power law in different countries to model variation of wind speeds with height in estimating the potential of wind power applications. These equations have not been applied or tested for the Lake Victoria shore. Below a certain height, wind speed varies with height mainly because of turbulence and temperature gradient. Above a certain height the atmospheric mean velocity approaches theoretical geotropic value; (Carruthers, 1943; Bechrakis and Sparis, 2000; Hsu, 2003).

Any law for wind speed variation with height therefore, applies only to a particular locality and temperature gradient. Justus and Mikhail (1976) proposed the symmetrical Weibull formula based on the power law and successfully used it up to 100 meters. Subsequently the power law has been used by researchers such as Hsu (2003). Lackner *et al.,* (2007) reviewed the potential errors and uncertainties in these equations. The power law is expressed in the form:

$$\frac{V_1}{V_2} = \left(\frac{H_1}{H_2}\right)^{\alpha} \quad \text{.......} (2.4)$$

where α is an exponent, V_1 and V_2 are the mean wind speeds at heights H_1 and H_2 respectively. The logarithmic law is expressed as,

$$\frac{V(Z)}{V(Z_1)} = \frac{ln\left(\frac{Z}{Z_2}\right)}{ln\left(\frac{Z_1}{Z_2}\right)} \quad \text{.......} (2.5)$$

where; V (Z) and V (Z_1) are wind speeds at height Z and reference height Z_1. Z_2 = roughness height. Equation 2.6 based on the power law is the Weibull extrapolation formulae and is used by Hennessey (1977); Tackle and Brown (1977); Shamshad *et al.,* (2003).

$$P(V)dv = \frac{c}{k}\left(\frac{V}{c}\right)^{k-1} \exp\left[\left(\frac{v}{c}\right)^{k}\right] dv \ldots\ldots (2.6)$$

$$\frac{K_2}{K_1} = \frac{1-0.0881\,\ln\left(\frac{Z_1}{10}\right)}{1-0.0881\,\ln\left(\frac{Z_2}{10}\right)} \ldots\ldots (2.7)$$

$$\text{and } \left(\frac{C_2}{C_1}\right) = \left(\frac{Z_2}{Z_1}\right)^{n} \ldots\ldots (2.8)$$

where;

$$n = \frac{0.37-0.0881\, lnc_1}{1-0.0881\, ln\left(\frac{Z_1}{10}\right)} \ldots\ldots (2.9)$$

The subscripts refer to heights one and two, P (v) = probability density function, c = Scale factor ms^{-1}, V is the velocity in m/s and k = shape factor (constant) and Z = height in meters

2.3 Wind pump Drip Irrigation System

The use of WPDI will require wind energy (EW), the water-pumping windmill (WPWM) and production resources (RP); weather, land, crops and soil. It thus forms a system that delivers water to the plant root. The nature of transformations of wind vis-à-vis the day spectrum characteristics to run windmill and pump water, to the drip irrigation characteristics are not adequately available. The WPDI development concept is therefore by taking cognizance of the existing hydraulic equations such as Hazen Williams and wind pump instantaneous discharge equations 2.10 and 2.11 respectively together with the resource equations (relating to crops and land) as the governing statements for a balanced discharge that needs to be investigated(Enciso and Mecke, 2004).

$$P = 0.0109D^2V^3 \ldots\ldots (2.10)$$

$$P = 0.002D^2V^3 \ldots\ldots (2.11)$$

where: P= Power in watts (note: 746 watts = 1 horsepower); D= rotor diameter in meters;

V= wind speed in kilometers per hour.

The WPDI system operation will thus be interpreted in terms of the predicting capability of instantaneous equations used, vis-à-vis the wind speed and discharge. Evaluation of the WPDI is then done on the basis of irrigation efficiency standard procedures and as feedback to formulations that relate governing discharge equations, from the wind rotor to the supply line and finally to the irrigation unit.

2.3.1 Water Pumping Windmill

The water-pumping windmill that was used with drip unit along the lake shore, was the horizontal axis type with a rotor (High Solidity type), pivoted freely on the tower for proper orientation to the wind, multi-blade and coupled to reciprocating piston pump. The design concept concerned the behaviour of the rotor in the wind, coupling to the pump, the safety mechanisms and the whole system unit for water delivery as work.

The basic principles of the wind rotor design are outlined in Vardar and Bulent (2006). The WPWM may be taken as a black box, with wind as input and discharge as output. The design concept concerns the behaviour of the rotor in the wind, coupling to the pump, the safety mechanisms and the whole system unit for water delivery.

The rotor blades operate in an air stream and experience a lift (perpendicular to the direction of undisturbed air stream) and drag (in the direction of undisturbed air flow) forces which are described by dimensionless quantities (Vardar and Bulent, 2006). Factors that affect the Betz's power coefficient are the rotation of the wake behind the rotor because of (the extra kinetic energy losses), the finite number of blades, (the air mixing at the tip (lip losses) and C_d/C_L ratio which does not go to zero. Radius of the rotor for example, in the case of the water pumping windmill is chosen with the required energy output $[E = 0.1\pi R^2 V^3 T (Wh)]$and design wind speed ($V_d$) which, can be put equal to the average wind speed where T = Period length in hours.

Wind pumps though have capacity limits due to the wind potential and they need judicious use when under taking irrigation. The combined systems (irrigation/wind pump) then become one of the choices for use for crop production.

Wind energy conversion systems (WECs) and drip-irrigation technologies as in this case, were developed separately in different parts of the world (WMO, 1981) for diverse purposes.

The WECs are used in agriculture, water supply, and other industrial applications, but vary on the basis of the state of wind technology, institutional framework and macro-economic factors in place. In agriculture WECs are mainly used for surface irrigation (Synman, 1980; Van Vilstren, 1980). In Kenya the Global Wind Pump Evaluation Programme (It Power Ltd) report of 1987 and Kruger Consult (1993), describes the potential of WECs in agriculture.

Wind energy over the past years however has sometimes been viewed negatively, often associated only with destruction of the environment - buildings, crops, evaporation from reservoirs and soil erosion (source).

Only until recently when characterization studies in various parts of the world by among others: - Carruthers (1943); Chipeta (1976); Hennessey (1977); Takle and Brown (1977); Stewart and Essen (1978); Justus *et al.,* (1978); Justus *et al.,* (1979); Van Der Auwera *et al.,* (1980); Qamar-uz-Zaman *et al.,* (2007) has enhanced its application as reviewed by WMO (1981); De Jongh and Rijs (2004); Yao *et al.,* (2011). The above literature is prerequisite reading for the planning and modeling of the wind pump - drip-irrigation (WPDI) for development of WECs in Kenya with respect to drip-irrigation.

High output in a windmill may condemn a low availability of wind speeds; hence it has to be matched to the available wind speeds. Four methods are available as is described in Lysen (1982) that is, the rule of thumb$[E = 0.1\pi R^2 V^3 T(Wh)]$, the graphical method, the computational method and the estimation method. These may not be adequate for planning a WPDI system at the Lake shore hence, the study on aspects and parameters for development of the WPDI.

2.3.2 The Drip System

In Kenya drip-irrigation is in its early stages and is mostly limited to backyard activities of horticulture on individual efforts. The system parameters on the other hand need to be designed with knowledge of the effects of (i) physical factors and (ii) the hydraulic factors to allow for; (a) sound operation and (b) checking of the specifications as diagnostic tools for maintenance (Bralts, 1981 a or b).

There is no hard rule about layout of the WPDI system but it is composed of; power source (water pumping windmill), main line, sub-main or manifolds, laterals, the emitters and controls which could be manual, partially or fully automatic, as elaborated in Kizer (2007).

The system to be used at the Lake Shore will have the drip unit directly coupled to a WPWM. The emitters that are considered the heart of a drip irrigation system are positioned along the laterals. The system capacity is determined based on the irrigation mode that is practiced within the project area and may be on rotation, free weekend operation or on demand. Power required is calculated based on discharge expected and the head that the energy source has to work against.

The windmill as the energy source is the added element to the design process equivalent to diesel or electric pump in the case of the WPDI. The other criteria to be determined for WPDI irrigation design processes are; crop water requirements, rainfall regime and problem of salts depending on their expected effects. These encompass aspects of evapotranspiration, crop factor coefficient (K_C), ground cover (GC), irrigation efficiency, concept of wetted portion (Wp) and their variation during the growth stages. The hydraulic design concept is based on Hazen – Williams equations. Nomographs for these are available as is documented in Schwab *et al.,* (1993), Karmeli *et al.,* (1985), I – PaiWu *et al.,* (1974), Jensen (1980) among others. Karmeli *et al.,* (1985), Vermeiren and Jobling (1980) in addition presents graphs of estimating the wetted diameter (Wd) and depths of the wetted zone on the total volume of water applied per irrigation. Karmeli *et al.,* (1985); Keller and Karmeli (1974) have further documented forms of empirical predictions for Wp. Field variations, however, exist in use of Wp due to soil type, hence field tests could be necessary. The advantages and disadvantages of drip irrigation as given in Dorata and Izuno (1997) need review with the case of design of a particular WPDI. The above aspects or parameters of irrigation designs design are brought to one house in the HydroCalc irrigation system planning software (Rareş, 2009).The software covers design of emitters; laterals sub mains, mains and efficiency of the drip irrigation.

a) Emitters

The emitters used with the WPDI system were; the pressure and the non-pressure compensating emitters. Their-discharges were characterized by the following equation (Karmeli and Keller, 1975):-

$$q_e = K_e H^x \qquad (2.12)$$

where: q_e = discharge of the emitter in l/hr, K_e = a coefficient specific to each type (based on Bernoulli and continuity equations), H = the pressure head at which the emitter operates in meters, x = an exponent, the value of which depends on the flow regime (turbulent, laminar or pressure compensating). The emitters in use differ in terminologies though, but the basic requirements should include; uniform and constant low discharge, sufficient aperture to prevent clogging, low cost, robustness and homogeneity as stated in Karmeli *et al.,* (1985).

The emitter's manufacture precision as a performance factor of the system needs to be considered for the WPDI just as the discharge pressure head (q-h curve) relationships. Details of these are found in the respective manufacturer's manuals and theory from standard irrigation textbooks. Variations have tended to be normally distributed and the term manufacturers' "coefficient of variation" (C_v) is used. It describes the expected discharge variation in a group of emitters (similar) when operated at nominal pressure taken as 10m head.

b) Laterals

The concepts for the WPDI lateral design are documented in Karmeli *et al.,* (1985); Schwab *et al.,* (1993); I-Pai Wu *et al.,* (1979); Vermeiren and Jobling (1980); Benami and Ofen (1983) for the constant head drip systems in obtaining the appropriate lateral size and hence uniformity of irrigation. The WPDI lateral design also is decided on by a rule of thumb just as for sprinklers; that a sprinkler's diameter is selected such that the difference in discharge between emitters operating simultaneously and in laminar flow shall not exceed 10% Karmeli *et al.,* (1985) and for turbulent flow the pressure variation should not exceed 20%. This uses analytical methods by consideration of uniform/tapered pipes vis-à-vis uniform emission (method of adjustments), non- uniform emission (method of degree of allowable variation) and the graphical methods such as the "polypot" technique as is described in Herbert (1971). A part from the effect of temperature, local head loss due to emitters or pressure distribution within the system should also be considered with regard to the topography and velocity of flow.

c) Main and Sub-Mains

Sub main design is as for a lateral line with a steady, spatially varied flow with laterals as outflows instead of the emitters. The lateral spacing is wider with larger discharge outlets.

Consequently the analytical techniques described for the laterals are applicable (I-Pai Wu *et al.*, 1979).

The WPDI mainline can be made of hard PVC just as laterals and buried to prevent the effect of sunlight, algae growth and external damages. Their design may be as simple as a single line to a particular field or a complex system that may involve many field layout considerations. Also the design of the mainline systems may not only involve optimization of a particular field layout but sometimes a matter of economics, especially when pressure regulators are used at the sub main entrances. Choice may therefore, be based on the cost of energy required to pump against friction head losses for different pipe diameters plus the capital costs on an annual basis. Pipe network and linear programming techniques may be used. Monographs based on Hazen-Williams equation for quick solutions are also available for the WPDI design.

2.3.3 Irrigation Uniformity and Efficiency

The effectiveness of the WPDI is based on the flow variation and uniformity evaluation equations, given in the form of equation 2.13, which has been modified severally. The equations for evaluation of WPDI are those of conventional drip irrigation as in Mofoke *et al.*, (2004) and can be developed mainly in relation to the coefficient of variation to take care of factors such as emitter manufacture, lateral line friction, elevation difference, and emitter clogging. The initial form was for trickle irrigation lateral only. Karmeli and Keller (1975) however indicated that this was also applicable to system emission uniformity by equation 2.13, while the other concepts are Emitter flow variation concept (I-Pai Wu and Gitlin, 1974) and the statistical uniformity concept (Bralts *et al.,* 1981a, 1981b).

$$E_u = 100\left(\frac{q_{min}}{q_{avg}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{2.13}$$

The commonly used equation is of the form;

$$E_a = K_s E_u \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{2.14}$$

where E_a is overall application efficiency in soil, K_s is water storage efficiency, E_u is field emitter emission uniformity as a percentage.

It has an effect on the design process in terms of the gross irrigation depth, irrigation interval, system capacity and selection of the emitter type.

Drip irrigation however is recognized to have high irrigation efficiencies (Dorata and Izuno, 1997) but is affected by the standard of the system design and management (Mofoke *et al.,* 2004). Hence before evaluation; the hydraulic design of the WPDI among other parameters should be sound to ensure proper operation with the knowledge of effects of; topography and hydraulic factors; and an evaluation in mind for the maintenance (Bralts, 1981b). It can be a method for increased food production, energy saving (Hardin and Lacewell, 1981) and alleviation of labour time. These benefits arise from; no surface runoff, deep drainage and limited evaporation as stated by Pande *et al.,* (2002) on tests on drip system by use of solar photovoltaic (PV) pump.

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CHAPTER THREE

VARIATION OF WIND SPEEDS AT THE SHORE OF LAKE VICTORIA (KENYA)

Abstract

The Kenyan Lake Shore (LS) covers an area of 5700 km^2 with few wind speed recording stations. Kisumu is the only station at the shore having continuous 2m and 10m height records available. The other weather stations (Rusinga, Muhuru, Ahero, Kadenge and Kibos) only have the 2m height data. Lack of verified constants for power law equations such as power law index (α) and logarithmic power law (Z_o) that relates wind speed variation with height, location and terrain contributes to difficulty in application of wind energy conversion (WECs) systems. The objective of this research therefore was to determine temporal and spatial wind speeds variation and its relationship with time, location and height within the LS. The 2m height data was analyzed to determine consistency (diurnal, monthly and seasonal trends, strength, duration and direction) with location and established direct and indirect use of the power law index (α) as a methodology that relates increase of the wind speeds with height. The power law index (α) relationship was used in estimating wind speeds at 10m for effective installation and utilization of the wind energy for water pumping. $WS_2 = 0.25WS_{10} = 2WS_{10G}$. It was established that, the wind speeds (2m) within the LS foremost fitted the three parameter Weibull distribution (α) index was averagely 0.4 for the LS, 2 times less the actual (0.8) for Kisumu and was negatively related to the power law index (α). The predicted Kisumu 10m wind speeds from 2m correlated well to actual 10m with R^2 above 0.8. The Weibull distribution parameters (the scale factor and the power law index) were found applicable in estimating wind speeds at 10m from 2m heights. Further hourly measured wind data for every month was found adequate in estimating the wind speeds at a particular site. Wind speeds were generally higher than 2m/s near the water body and mainly in two directions (North and South western). This is indicative of greater wind potential at the shore line and an established orientation for installation of wind pumps for exploitation of wind energy.

Introduction

The wind speed records within the Lake Shore are inadequate and scanty with only a few stations having continuous records. Oludhe and Ogalo (1990) characterized the wind speeds in Kenya and concluded that there is wind potential for pumping and electricity generation. This study hence explored the spatial and temporal variation of wind speeds from the 2m wind speeds records available within the Lake Shore (LS) and predicted to the 10m height by direct and indirect methods, which were developed.

In wind energy conversion systems (WECs), wind speed is critical in determining the extractable power for use. Due to the cubic relationship of velocity and power, a smaller variation in wind speed results in a larger power output, hence, because of this phenomenon, knowledge on wind variation in relation to both altitude and height of measurement above the ground surface is of great importance. Analysis of the changes of wind speed with height has also been investigated. Sisternson *et al.,* (1983); Holt and Wang (2011) studied the suitability of using power law equation to predict wind speeds at different heights with success. They also noted that during night time, wind profiles measured were far from the derived values of the power law equations.

The quantification of the available wind speed is important for matching the wind pump rotor size and its intended use including water supply and electricity generation among other uses. The variability of wind speed magnitude in relation to location, height, altitude and time determines the wind energy exploitation potential. This is because wind is site specific. Proper matching and sizing of the windmill is key in achieving efficient and reliable outputs.

Wind energy on the earth's surface is due to the incident solar radiation which causes temperature difference between tropics resulting to air motion. The need to evaluate extractable wind power for human use is important. The commonly used wind pumps operate at a height of 10m or higher (WMO, 2006). This height is chosen due to less interference to wind flow by topographical features and buildings. Lack of enough data is an inherent challenge in extraction and utilization of wind energy within the LS. There is need to understand the trend and profiles at 2m height within the LS from the available data so as to predict the wind speeds for different locations and the 10m height for installation of wind conversion systems.

The interest on wind power and the desire for green energy has prompted research on wind potential and use. Many researchers Doran and Verholek, (1978), Yilmaz and Çelik (2008), Kostas and Despina, (2009) show the various methods of wind speed estimation which include: observation, graphical, empirical and statistical formulae.

The increase in energy demand, the increasing shortages of fossils fuels in the world and the desire for green energy has necessitated utilization of the wind resource. Wind speed is critical since it determines the extractable wind power and the subsequent performance of wind conversion systems. Probability distribution time of wind speed can be determined and used to estimate wind potential. The Weibull function is widely used because of its two flexible parameters namely the shape parameter which describes the width of data distribution and the scale parameter that represents the range of distribution. Wind characterization and operation of a wind conversion system such as WPDI, is not an exception and is to be done with respect to the day wind speed spectrum with a chosen wind speed interval. Use of wind machines therefore needs knowledge of wind speed potential at given sites, duration, strength and its variations with time. There is need to develop a wind speed estimation method both at a location and at a higher height where there is no 10 m height wind speed records, especially for the LS.

Most wind turbines including water pumping wind machines operate in such a way that there is an initial velocity (V_{in}) when the rotor starts, design speed (V_r) and the furling speed (V_{out}) where the wind pump rotor is stopped or deflected out of the wind stream by the safety mechanisms (Ramesh *et al.,* 2011). The availability of the rated wind speed (V_r to V_{out}) and any speed between V_{in} to V_r may only be possible for a percent time of a day's wind spectrum; hence the need to analyze the spectrum (temporal variations) and quantify it for operation of a wind turbine.

a) Wind Speed Variation with Height

The variation characteristics of wind speeds with height are mainly established/ evaluated by use of the power law, logarithmic wind power law and Weibull Extrapolation formulae. Power law has been used by various researchers, with variations in outputs. Tsang *et al.,* (2002) assessed the wind characteristics in Taiwan by site pre- determined alpha index (α) and another constant δ based on wind speed at the boundary layer height. The values for these parameters were estimated by Taiwan Central Weather Bureau with regard to the local topographic conditions surrounding the stations. Ray *et al.,* (2006) used the power law index to estimate the wind characteristics in the United States. Oludhe and Ogalo (1990), characterized surface wind speeds in Kenya by the Weibull extrapolation formulae from a number of stations, where the LS was represented by the Kisumu station. These prediction equations have been used by other researchers such as Celik (2003), Olaofe and Folly (2012) with sufficient accuracy. For wind speeds under adiabatic conditions and for sites with uniform terrain or roughness and with uniform temperature within the first 50-100 m or with linear temperature decrease with height at a rate of 1° C per 100m then, the logarithmic height law has a higher degree of approximation (WMO, 1964. Panofsky, 1973, Hsu *et al.*, 1993) and are given in equations 3.1 to 3.3.

$$V_B = \frac{u^*}{\eta} \ln \frac{h_B}{Z_0} \quad \text{.......} \quad (3.1)$$

$$\frac{V_B}{V_A} = \frac{\ln \frac{h_B}{Z_0}}{\ln \frac{h_A}{Z_0}} \quad \text{.......} \quad (3.2)$$

Hellman's power equation is given as:

$$Z_0 = \exp \frac{h_B^{\alpha} \ln h_A - h_A^{\alpha} \ln h_B}{h_B^{\alpha} - h_A^{\alpha}} \quad \text{.......} \quad (3.3)$$

where, V_A is the mean wind speed at reference height, V_B is the mean wind speed at height B, u^* is the frictional velocity (equivalent to the ratio of the surface stress to the density,($\sqrt{\tau/\rho}$); η is the von Karman's constant ≈ 0.4;h_A is the reference height where wind speed V_A is measured, h_B is the height at which the wind speed V_B is measured; Z_o is the surface roughness coefficient (Asmail and Ali, 2010); ρ is the air density and τ is the drag per unit of the boundary layer). Typical values of u^* may be obtained from Deacon (1949) and Priestley (1959). The values of Z_o are in the order of 0.001 to 100 cm for various descriptions of terrains as reviewed by Davenport, (2000) and WMO (2006) as shown in Table 3.11 for Kisumu 1995-2011 in the appendix. The use of these values of z_o has been reported by Asmail and Ali (2010); Oludhe and Ogalo (1990) among others.

The logarithmic law does not give sufficient accuracy and could be more complicated in some instances for the Lake Shore region due to varied terrain and the proximity to the water [illegible] than the power law approximation with the Hellman's shear exponent (power law index, α) which offers sufficient approximations for most engineering tasks.

The power law (equation 3.4) is easy to use. The form of expression for increase of wind speed with height, especially when α is 0.143 also known as the $1/7^{th}$ power law (Kamau *et al.*, 2011) is;

$$\frac{V_B}{V_A} = \left(\frac{Z_B}{Z_A}\right)^{\alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

where α is Hellman's shear exponent (power law index α) z_B and z_A are mean wind speeds at the respective heights and V_B and V_A are mean wind speeds at heights A and B The wind speed alpha index (α) is not the same for different locations, seasons and must be determined for every station.

Like the logarithmic equation, the power law equation has inherent shortfalls in that wind speeds below the reference height are affected by obstacles in the terrain which cause decrease in wind speeds. Wind speeds above the reference height, increase with height due to reduced roughness. Emeis and Turk (2007) noted that the power law offers a nearly perfect fit under stable atmospheric conditions with certain surface roughness and good approximation under neutral and unstable conditions in the limit of very smooth surfaces.

As for existing equations (3.1to 3.4) for increase of wind speeds and height, none has the direct application to the situation at the LS. The equations may not be applied directly to determine the wind speed in any particular site except the $1/7^{th}$, which has a shortfall in that it underestimates the magnitude of the wind speeds for the LS (Oludhe and Ogalo, 1990). The power law (3.4) and the Hellman power equation (3.3) though available for use, the parameter (α) in equation 3.4 is used when the wind speeds conform to the Weibull distribution or conditions are adiabatic and favours the $1/7^{th}$ rule or that the alpha index α be determined. Justus *et al.,* (1976a, b) used the Weibull distribution to represent the wind velocity probability density function. Justus *et al.,* (1976a) and McIntyre et *al.,* (2004) proposed equations (3.5 to 3.8) which allow extrapolation to be made using the scale factor c and the shape factor k.

$$p(v)dv = \left(\frac{k}{c}\right)\left(\frac{k}{c}\right)^{k-1} exp\left[-\left(\left(\frac{v}{c}\right)^{k} dv\right)\right] \quad (3.5)$$

where; $p(v)$ is the probability density function for the Weibull equation.

Other formulae based on the power law are:

$$\mathrm{k}_1/\mathrm{k}_2 = \left[1 - 0.00881\ln\left(\frac{\mathrm{Z_A}}{10}\right)\right] \Big/ \left[1 - 0.00881\ln\left(\frac{\mathrm{Z_B}}{10}\right)\right] \quad (3.6)$$

and

$$\frac{c_2}{c_1} = \left(\frac{\mathrm{Z}_2}{\mathrm{Z}_1}\right)^{\alpha} \quad (3.7)$$

where

$$\alpha = [0.37 - 0.0881\ln(\mathrm{C}_1)] \Big/ [0.37 - 0.0881\ln(\mathrm{Z}_1)] \quad (3.8)$$

The subscript 1 and 2 refer to the lower and upper levels (below and above the reference height), α is an index, Z refers to the height in meters and *C* is velocity in meters per second. k1 and k2 are constants. Doran and Verholek (1978) cautions on the use of the above formulae for extrapolation of mean wind speeds due to scatter of data used in its development.

The need for establishment of the variable power law indices α and z_o which are site specific and are critical in wind speed calculations is often emphasized (Ray *et al.*, 2006). Kisumu station is the only one where z_o and the power law index could be calculated using the available data at two heights and the extrapolation equations could be applied. The rest of the stations at best are estimates because not all the parameters in the extrapolation equations are available within Lake Shore unless a statistical distribution that conforms to wind speeds at a location is first determined and applied.

Much research has been carried out, but there are difficulties in relating wind profile; wind speed power law index (α) and the logarithmic power law $\mathrm{Z_o}$ (site specific) together. The LS situation is further complicated by availability of only records at 2 m height while WPDI requires more than 10 m high (WMO, 2006). The spatial and temporal variation within the LS is hence analyzed in the context of fitting wind speeds to the Weibull distributions and using the extrapolation parameters to identify the potential for WPDI.

Wind density functions have been used in wind analysis, such as the Weibull and Rayleigh distributions by Tsang *et al.,* (2002), Pallabazzer (2003); Ray *et.al.,* (2006); Nfaoui *et al.,* (2003) and Asmail; Ali (2010). In this research, attention was given to the Weibull distributions because the data conformed to the tests of fit and ease of determining the distribution parameters. Furthermore, it had been used by Oludhe and Ogalo (1989), in this LS region to characterize the Kisumu wind speeds with success.

Wind Distributions Functions

Many probability distributions have been used to find the best fit for wind data including Beta, Exponential, Negative Exponential, Largest Extreme Value, Smallest Extreme Value, Gamma, Johnson, Log logistic, Lognormal, Normal, Pearson, Uniform distributions and Weibull statistics. The Weibull distribution is emphasized because it has been applied in various locations by authors such as Rehman *et al.,* (1994), McIntyre *et al.,* (2004) in surface wind speed (10 m and above) analysis and it is characterized by the equations 3.9 and 3.10:

$$f(v) = \frac{k}{F(v)}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \quad \text{...}(3.9)$$

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \quad \text{...}(3.10)$$

where: $f(v)$ is the probability density function, $F(v)$is the cumulative distribution function, c is the scale parameter with units equal to wind speed units, k is a dimensionless shape parameter and v is the wind speed. Notably the higher the value of c the higher the wind speed, k shows the wind stability. The scale and the shape parameters can be estimated by both the method of maximum likelihood and the method of moments as is given in equations 3.15 to 3.20 in appendix.

In their study of the statistical characterization of wind speeds in Kenya, Oludhe and Ogallo (1989) also concluded that the three -parameter Weibull distribution is the best fit distribution describing the statistical characteristics of the maximum, minimum and mean daily surface (10 m) wind speeds.

objective of this study on wind speeds at the LS was:

To determine the temporal and spatial wind speed trends and profiles at selected Lake shore sites.

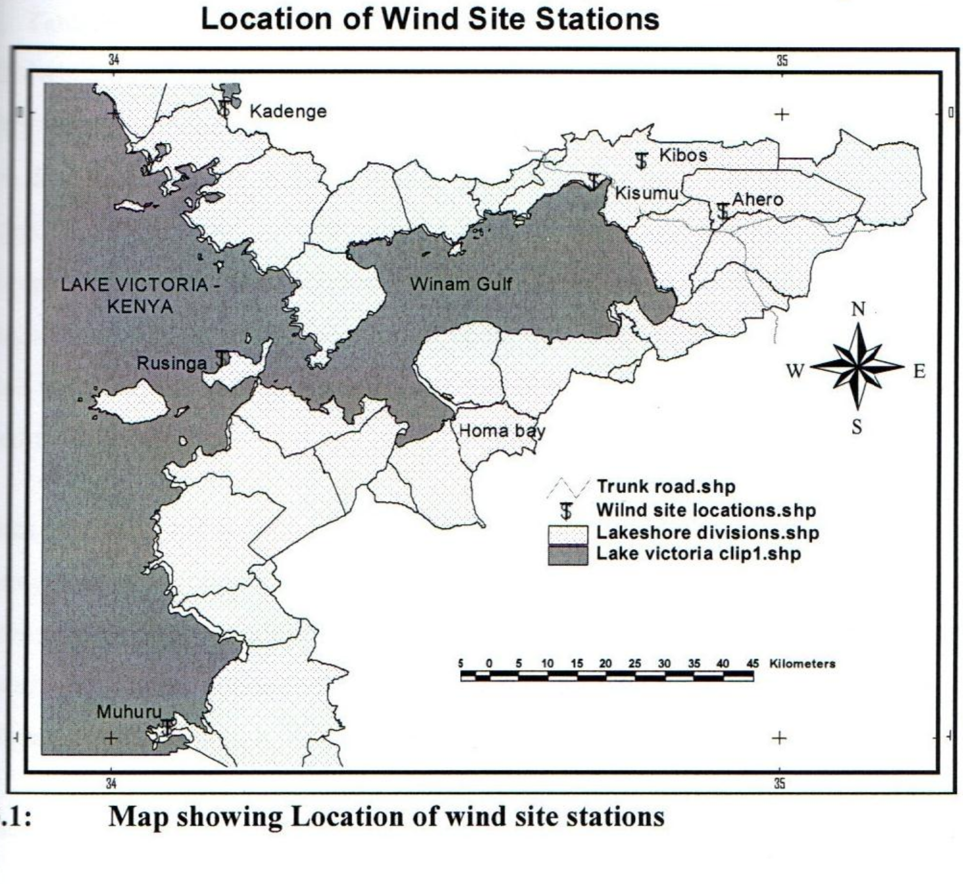
To develop an empirical relationships of wind speed and height at the shores of Lake Victoria Kenya.

To develop empirical relationships of wind speed and location; and magnitude at the shores of Lake Victoria Kenya.

Materials and Methods

Study Area

area studied is delimited by contour 1200 m a.s.l and a 40 km distance on average from Lake shoreline and constitutes the Lake Shore (LS) area as shown in Fig 3.1 below.



3.1: Map showing Location of wind site stations covers an estimated area of 5700 Km^2 from Muhuru Bay in Migori County to Busia County in Kenya excluding the lake water surface area (4113 Km^2). The Lake shore (L) S area is characterized by low slopes (<2% near the shore about 1100 m a.s.l), a rising middle area and a highland zone of contour above 1200 m. Much of the area is within the ecological zone 3 and 4 with distinctive weather indicating limited and poorly distributed rainfall for crop production. Land use in the area is largely rain fed (with minimal irrigation practice) small scale crop production, livestock and settlement (Townships, villages and homes).

The data used were mainly collected for agricultural purposes at the 2 m height by the three cup anemometers, read manually except for the 10 m wind speeds of the Kisumu station that were automatically recorded. The data from 1996 to 2011 for Kadenge, Rusinga, Ahero, Kibos Cotton and Muhuru Bay were used.

The raw wind data was obtained from the Ministry of Water and Irrigation except those of Ahero and Kibos which were from the individual weather stations. The data was hand recorded and later keyed into a computer for the purpose of analysis. The monitoring equipment used in the weather stations included tilting siphon, rain gauge, sunshine recorder, evaporation pan, hygrometer, thermometer, wind vane and cup anemometer.

3.3.2 Temporal and Spatial Wind Trends

The 2m wind speeds were evaluated based on geographical area to show hourly, diurnal and monthly variation, wind direction and annual averages. These were considered as consistency aspects for projecting the wind speeds to 10m. The 2m height records used were obtained from the six LS weather stations namely; Kisumu, Kadenge, Muhuru Bay, Rusinga Island, Ahero and Kibos Cotton. The recorded data at 10 m height for Kisumu and 2m height for Kadenge were used for projecting diurnal variations. Uniformity and consistency of data was checked by fitting the data to Weibull distribution formula. Missing data was interpolated and verified for conformity.

The data from all stations records from 1996 to 2011 were arranged by year, month and day including annual averages. The data below 1996 was excluded in the analysis due to lack of consistency and non-availability from some of the stations. The five variations examined for temporal and spatial characteristics of wind speeds within the LS were; annual/monthly; daily/hourly, wind direction, location and heights.

Statistical distribution of parameters that would result to the best fit of data was examined and determined, mainly to obtain location (ε), scale (c) and shape (k) factors which enabled prediction of the wind speeds beyond the 2 m height. Selection of a suitable statistical distribution for the stations that fitted the available wind speeds was then carried out by use of the distribution analyzer by Taylor Enterprises Inc. (2007) and the Minitab statistical software (2011) from the 2m height data. Equation 3.8 was used to determine (α), while the scale factor (c) was determined from the distribution that fitted the wind speeds data to Weibull model. This was subsequently substituted in equation 3.4 with the stations known heights and wind speeds, as it was noted that equation 3.4 and 3.7 are related. The alpha α index and profile values were calculated for the LS 2m data. The relationship of alpha α, location and wind speeds from calculations were then amplified by relevant respective graphs. It was the basis of projecting wind speeds of Kisumu 2m data to 10m.

The general test of fit of the data to the statistical distributions was carried out for all the stations and the parameters determined for three scenarios; i) all data for every month put together as one data set for all the years; ii) average of a particular month (January to December) for all years; iii) a month's data randomly selected (January to December) for Kisumu site among the six stations. Minitab statistical software (2011), Meyer *et al*., (2004) was used to analyze the data for Weibull, Gamma and lognormal distribution which are frequently used in wind analysis. The years taken for this analysis were from 2006 to 2011. This procedure was used to determine the descriptive statistics and the pre-requisite statistical p (confidence level) values for test of conformity for each of the statistical distributions. The procedure was repeated for Kisumu data only for the averages, case (ii). In case (i), the data was also tested for normal distribution. Results tables were generated to show conformity of the data to the Weibull distribution

3.3.2.1 Temporal Wind Variation

In order to analyze the hourly wind speed changes for Kisumu station as a specific example, data was first divided into four seasonal groups of December-March (dry period), April-July (wet season) and August- November(moderate rains). The alpha values were regressed against the annual wind speed for each quarter. The daily wind speeds as described were analyzed by use of distribution analyzer (Taylor Enterprises Inc, 2007). The Taylor analyzer gives a statistical distribution and the parameters thereof. This was to determine the viable distribution for the data category and confirm the variability of the parameters Weibull and the statistical p values for conformity. The out of range values identified, were removed without loss of generality from the calculations for two situations; i) in determining the scale factor for extrapolation of the LS stations wind speeds, and ii) when confirming that average of the winds speeds for the years available also followed the Weibull distribution.

3.3.2.2 Wind spatial relation

a) Relationship between the 2m and 10m Wind Speeds

The approach used in determining the relationship between the 2m and 10 m heights was twofold, direct and direct indirect. The direct approach was applied for Kisumu and Rusinga that had limited 10m data while the indirect approach was established for the LS stations that had no 10m wind speeds.

The direct relationship was established by determining power law index (α) from the Kisumu and Rusinga actual data available by use of equation 3.4. The 2m and 10m wind speeds for the years available for Kisumu was each divided into two equal sets (1996-2011, 2006-2011) respectively. The first set was used to determine the wind speed power law index (α). The α obtained with the first set of 2m wind speeds was used to predict the 10m wind speeds with the second 2m set of data (years). The actual 10m wind speeds for the second set and the predicted were then regressed and compared. The limited data for 2 and 10 m wind speed available at Rusinga was used to determine wind speed power law index (α). The resulting α for Rusinga was then compared to those of Kisumu. This was for the purpose of determining the universality of α index for the LS. The indirect relationship was applied to the LS stations that had only 2m height data, by first determining their conformity to Weibull distribution (Section 3.4.1.1) and secondly, through use of the resulting parameters (location factor: ε; c; k) in extrapolation to the 10m wind speeds. The wind speed law index (α) for each month for each station was then determined by use of equations 3.4 and 3.8. Furthermore, linear, quadratic and cubic relationships were determined by the Minitab statistical software (Minitab, 2000) including the projected data, to find out the usefulness of these other relationships.

b) Relationship of Wind Speed and location

After determination of (α) as in section (a), analysis was done by plotting average wind speeds against the wind speed law index on annual quarters (defined as dry, wet and moderate wet). Also ratios of wind speeds for the 2m and predicted 10m-height were determined with respect to the locations so as to verify whether there could be validity for use of ratios in projecting wind speed with height. It be noted that the magnitude was a factor that was determined directly or indirectly in all of section 3.2 for the wind speed relationships.

3.4 Results and Discussions

3.4.1 Geographical Area

The geographical characteristics of the Kenyan LS (Fig 3.1in section 3.3.1) has meteorological stations that lie within the altitude and distance range of 1100 to 1340 m (a.s.l) and 2-40 km distance straight line from the Lake shore. Kisumu, Rusinga and Muhuru Bay are close to the Lake (<2 km), while the rest of the stations are slightly further inland (<20km). The Kenyan gulf is 6% of water surface, 17% of shoreline length and 21.5 % of the catchment of Lake Victoria. The other details are as in Table 3.1 that gives distance from the Lake, longitude, latitude and duration of the data available.

Table:3.1: Geophysical Characteristics of Kenyan LS weather Stations

Location	Altitude (m)	Data Duration (height)	Latitude (Deg)	Longitude (Deg)	Distance from lake (km)
Kisumu*	1146	2006-2011 (10m) & 1996-2011 (2m)	00° 06’S	34° 45’E	2.04
Kadenge	1340	1996-2011 (2 m)	00° 02’N	34° 28’E	18.66
Rusinga	1240	1996-2011 (2 m)	00° 30’S	34° 15’E	0.1
Muhuru	1120	1996-2011 (2 m)	00° 10’S	34° 55’E	0.2
Kibos Cotton	1280	1996-2011 (2 m)	00° 04’S	34° 49’E	7.02
Ahero	1120	1996-2011 (2 m)	00°09’ S	34° 56’E	16.53

Wind distribution is dependent on temporal, spatial and breezes in the lake shore region and this also influences duration and strength (magnitude) of the wind speed, as is from observations, and as the results show or imply in the presented subsequent subsections.

3.4.2 Temporal and Spatial Distributions

3.4.2.1 Temporal Wind Distribution

The average monthly and annual wind speed distribution for the stations along the Lake Victoria shore is as presented in Table 3.2 and Figure 3.2 below. The minimum and maximum average mean monthly wind speeds (at 2 m height) are as underlined; 1.15 and m/sec for Kadenge, 1.12 and 1.72 m/sec for Kisumu, 2.23 and 3.02 m/sec for Rusinga respectively.

Table:3.2: 10 Year Average Monthly Wind Speed at Lake Shore Stations

Month	Ahero	Muhuru	Rusinga (m/s)	Kibos	Kadenge	Kisumu	Avg
Jan	0.91	2.53	2.87	1.04	1.5	1.57	1.74
Feb	0.97	2.63	3.02	1.15	1.61	1.7	1.77
March	0.96	2.71	2.98	1.13	1.63	1.72	1.86
April	0.86	2.33	2.55	0.82	1.37	1.38	1.55
May	0.72	2.25	2.23	0.71	1.16	1.12	1.37
June	0.7	2.29	2.27	0.68	1.15	1.12	1.37
July	0.72	2.47	2.4	0.7	1.24	1.27	1.47
Aug	0.76	2.71	2.55	0.76	1.35	1.44	1.6
Sept	0.83	2.84	2.6	0.84	1.41	1.46	1.66
Oct	0.78	2.78	2.59	0.88	1.38	1.38	1.63
Nov	0.77	2.55	2.54	0.88	1.34	1.38	1.58
Dec	0.85	2.48	2.75	0.96	1.45	1.49	1.66
Average	**0.82**	**2.55**	**2.61**	**0.88**	**1.38**	**1.42**	**1.61**

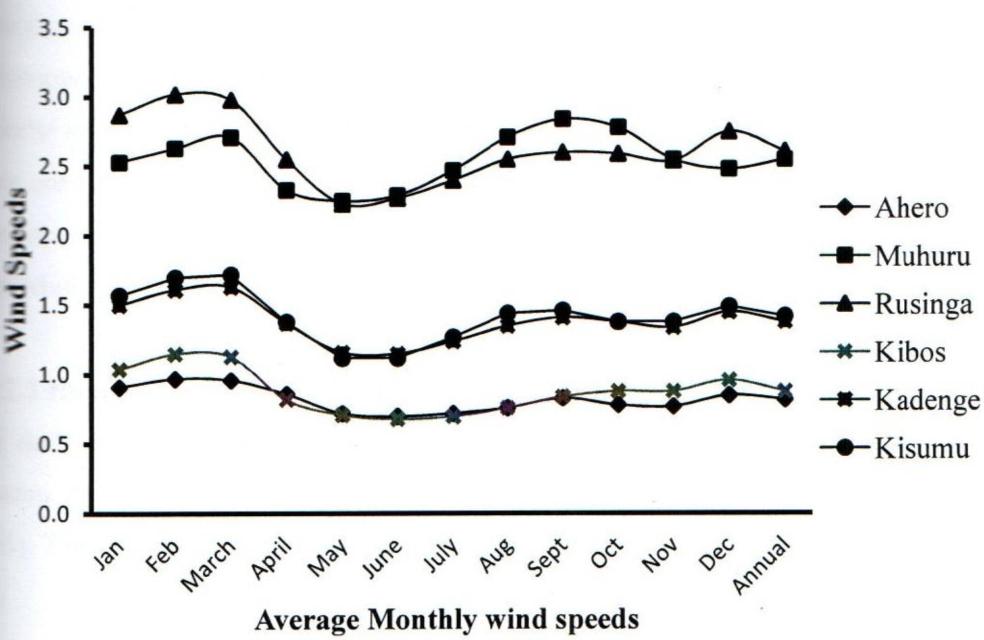


Fig: 3.2: The Lake Shore 15 yr Average Monthly Wind Speed

It is evident that the mean monthly wind speeds differ for Muhuru and Rusinga compared to Kadenge and Kisumu and for Kibos and Ahero. Muhuru and Rusinga are close to the lake shore and are more exposed to higher average mean wind speed; followed by Kadenge and Kisumu, while Kibos and Ahero have low average mean wind speeds Table 3.2 and Figs 3.1 and 3.2. This is attributed to distance from the lake, frictional factors from the land and fetch distance (distance before the wind reaches a station with uniform surface). The stations close to the lake have high wind speeds due to longer fetch distance on the water side and low frictional roughness due to the uniform water surface and effects of temperature on both land and water surfaces that cause breezes as observed from Table 3.2 and Figs 3.1 and 3.2. The further the stations inland the lower the wind speeds due to the increase in surface roughness caused by vegetation and built up areas from observation. Fig 3.1 and Fig 3.2 above further show the effects of spatial locations of the stations with respect to the water body. This is confirmed by (WMO, 2006).

3.4.2.2 Effect of Seasons on Wind Speeds

All the stations as in Table 3.1 had low average monthly wind speeds between April and July. The maximum monthly mean wind speeds occur in the month of February to March. Another peak though slightly lower occurs between September and October (Table 3.2 and Fig 3.2). This supports the observation that maximum wind speeds occur in the dry and moderately dry periods/ months, while the low wind speeds are in the wet periods. In any year therefore, there are two peaks (high and moderate) and one low wind speed period. The season of December to March temperatures are always higher than any other season and correspond to high wind speeds in the lake shore as shown in Figure 3.2 and Table 3.2.

3.4.2.3 Hourly and Daily Wind Speeds

The daily and hourly wind speeds within the LS is best represented by data available at Kisumu for six years (2006 to 2011) and Kadenge station (December 2004 and January 2005). The data is presented in appendix especially for Kisumu and shown in Figures 3.3 and 3.4.

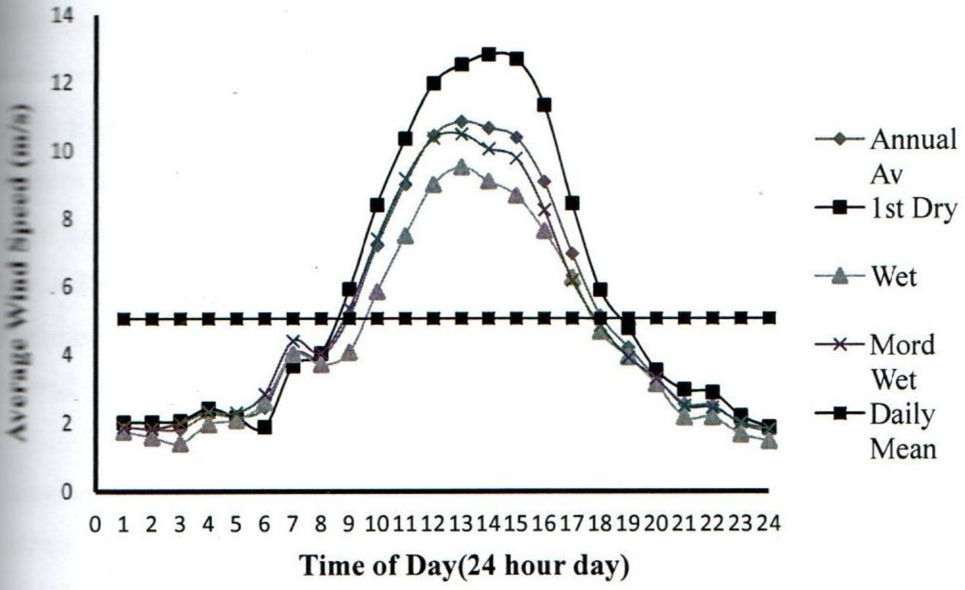


Fig: 3.3: **Hourly 10m Height Wind speed at - Kisumu Airport (2006-2011)**

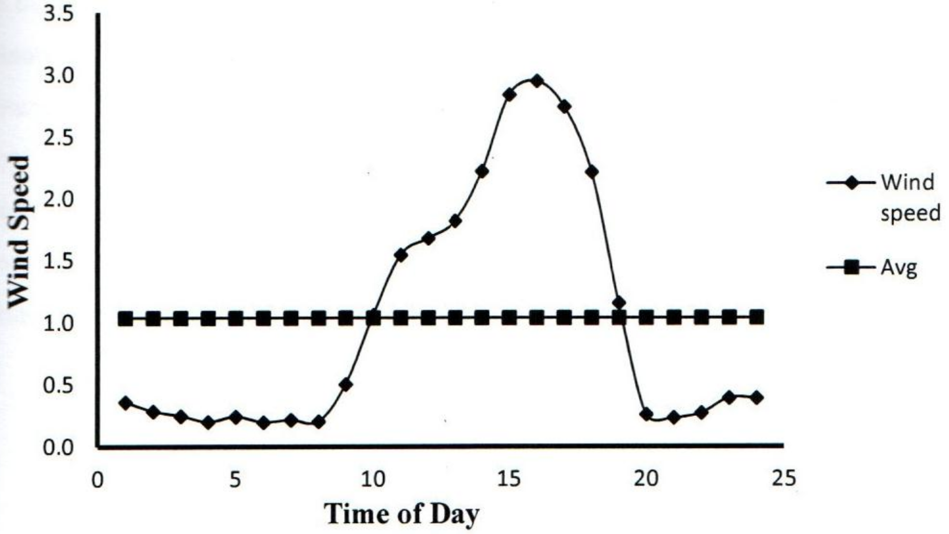


Fig: 3. 4: **Hourly 2m height Wind Variation at Kadenge.**

The hourly variation of wind speeds and its bell shape was confirmed and as reported by Ray *et al.*, (2006). The average mean wind speed is 5.07 m/sec at 10m height for Kisumu and while it is 1.00m/sec for Kadenge at 2m height (Table A3.6 in the Appendix). The breezes are common between 09 to 21 hours (Fig 3.3 and 3.4). The land breeze starts from 09 to 18 hours and the sea breeze starts at 1900 hrs ends by 00hrs, the rest is calm period between 01 to 08 hours.

The Kisumu 10m height (Fig 3.3) shows the diurnal wind speed (temporal) depended on the seasons (long rains, short rains and the dry periods) increasing from a minimum of 2m/sec at [illegible] to a maximum 5.8 m/s at about 1530 hours and then reduces to 2m/sec at about 2330 hours. At Kadenge (2m height), it starts at about the same time and drops to 1m/s by 2100 hours three hours ahead of Kisumu. This is attributed to height of measurement where Kadenge and Kisumu respectively had 2m and 10m measurement heights. Apart from altitude differences as in Table 3.1, Kadenge was also close to Yala swamp, within 2.5 km. This implies that effective energy utilization is between mid-morning and late afternoon when wind speeds are highest.

The seasonal (dry, moderate and rain) and annual variations follow a similar trend (Fig 3.3). The annual average being lower compared to the dry season and higher than both the short rains and for the long rains. This is due to low temperatures during the rain seasons. Seasons and annual averages converge to low wind speeds of about 2 m/s for Kisumu. It was observed that wind speeds within the LS depict the same temporal variation (within the hour, the days and the months). The threshold wind speed (2m/s) for a wind pump is available from 0930 to [illegible] hours at Kisumu. The hourly variation is important for analysis of the site specific performance of wind energy conversion (WEC) machinery or equipment especially for water pumping in terms of duration of water supply. The hourly daily wind data give a more clear indication of the wind speed for use in irrigation than the monthly data. The Figures 3.3 and 3.4 above demonstrates that hourly wind speeds or shorter time step is key to estimation of the duration and the strength of average wind speeds than Fig 3.5 below which masks the details.

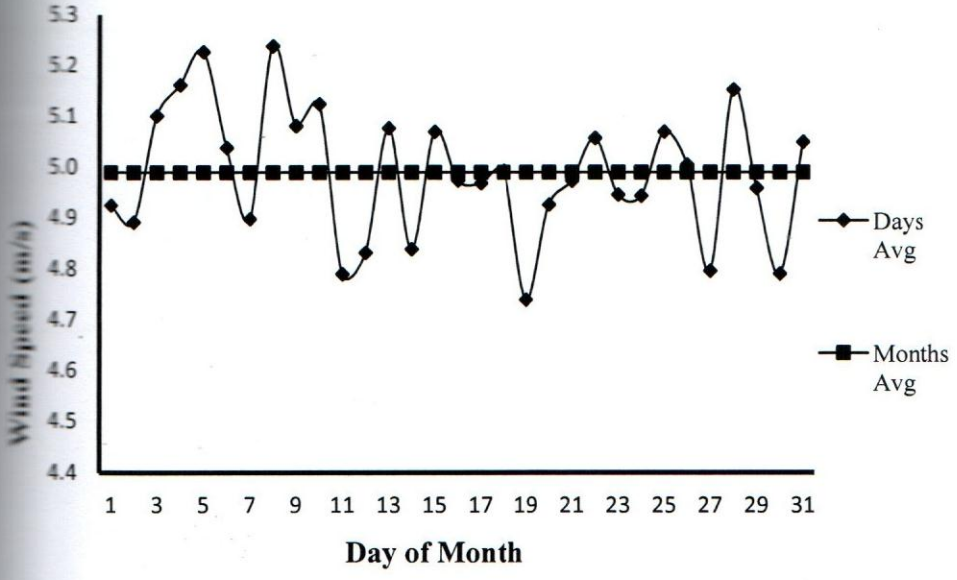


Fig: 3.5: **Annual Daily (Average 10m) Wind Speeds- Kisumu**

3.4.2.4 Temporal and Spatial Wind Direction

Wind direction of the three category sites (Muhuru and Rusinga, Kibos and Ahero, and Kadenge and Kisumu) within the LS is best illustrated by use of data from Kisumu of the years 2006 to 2011, since this was the only available representative data. The direction is significant as one considers installation of wind energy converters, types, discharge and orientation. The data in other stations was always observed at 0900 hrs hence wind direction is northerly.

The general wind direction is mainly Northerly 3/4 of the day with only Westerly direction in 1/4 of day as illustrated in Fig 3.6 derived by dividing the wind speed strength into categories (0-2, 2-4, 4-6.) m/s and time into quarters (07:00-12:00, 13:00-18:00, 19:00-24:00 and 01.00-06:00). The time based quarter diagrams in Figure 3.6 shows that at any one quarter the winds at Kisumu flow in one major direction; between 7.00 -12.00 a smaller magnitude flows in the Easterly and Southerly directions. The quarter diagrams that were constructed from Frequency tables shows that wind speeds are in the range of 2-4 m/s which is within the usable portion. It can also be seen that that change of direction is only in one quarter within the span of 24hrs when the wind flows South West.

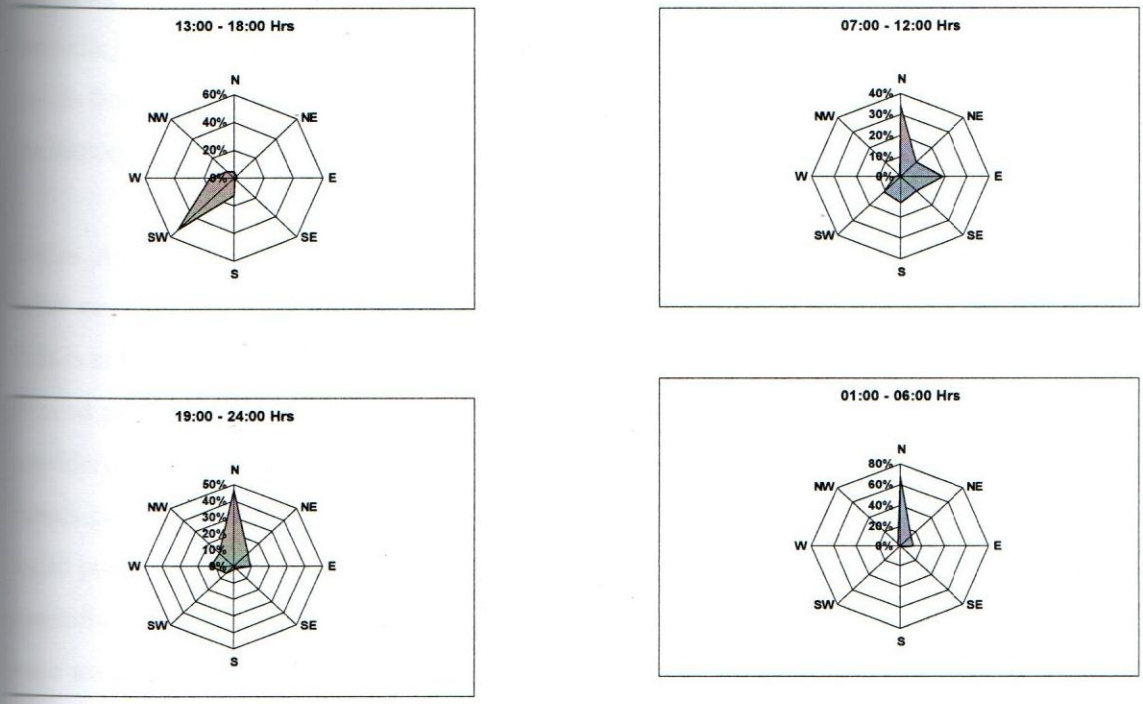


Fig: 3.6: Kisumu Wind Direction at different times of day

3.4.3 Spatial Variation

Proximity to water body influences wind speeds, due to the nature of the water surface which is horizontal, uniform and homogeneous. This is attributed to physical processes associated with the waves, surface currents, and heat transfer in the water body; and reference to Table 3.1, 3.2 and Fig 3.1 show that wind speed increases with decrease in proximity to the Lake Shore line.

3.4.3.1 Indirect wind speed determination.

The probability density function as discussed in section 3.3.2 (the indirect method in this case) is a procedure that was used in estimating the wind potential within the LS. Daily wind speeds taken for a particular month (January) for a number of years together did not fit the Weibull distribution in most cases for all the stations. This though succeeded in the case of a particular calendar Month tested independently for all the years and other months. However, very few grouped data points from similar months fitted the Weibull distribution. Table A3.7, A3.8 and A3.10 in the appendix shows the Weibull parameters for the LS stations. These include location, scale, shape and P –values. Kisumu as an example has been represented by the years 2001 and 2011 with descriptive characteristics shown in Table A 3.11 in the appendix. Tables 3.3 and A3.9 in the appendix also respectively show i) increase of wind speeds from 2 m to 10 m by use of the calculated alpha. ii) The % increase of wind speeds for the stations. These are also consistent.

Tables A3.7, A3.8, A3.9 and A 3.11 in the appendix, show that to use Weibull equation, either monthly averages for a number of years or a particular year data gave similar result. This is emphasized by Tables A3.10 and A3.11 in the appendix in the case of Kisumu which showed negligible inconsistency in only the positions marked for the large number of years considered. The performance of the three parameter Weibull distributions of average wind speeds per LS station for the months of the year shows that the range (start and end) of wind speed potential can be easily identified for each station for each month (Figure B3.11 in the appendix). The determined Weibull parameters (after test of fit for the data for distribution) were used in the extrapolation of wind speeds from 2m to 10m LS stations. The Weibull parameters were derived from each station's data hence reflected the conditions of the particular station. The logarithmic power law, the ordinary 1/7th power law extrapolation methods registered lower magnitudes of the wind speeds. The basic approach was therefore to use Weibull for extrapolation within the LS to determine the wind potential.

3.4.3.2 Wind Relationship with Height

The wind speed law indices (α) determined from the first set (2006-2008) of 2m and 10m height data are as in Table 3.5 below and in Table A3.12 in the appendix for Kisumu and the LS. The predicted 10m wind speeds from the second (2009-2011) 2m and 10m data by use of the α compared well at 95% confidence limit with actual 10m wind speeds (Table 3.3). Start zero values were used as is usual with wind speeds. A line scatter without zero values fluctuated bound horizontally with negative R^2 values. The annual scatter diagram showed a good relationship ($predicted = 1.1Actual$) of predicted 10m wind speeds from 2m wind speeds and actual 10m wind speeds of Kisumu, with R^2 of 0.84. Seasonal R^2 ranged from 0.54 to 0.7. A visual plot of the predicted compared to actual on daily basis is as in Figure 3.7 below. The predicted is higher than the actual wind speed which can be attributed to the difference in height and the equipment. Working with limited data from Rusinga 10m wind speeds gave wind speed law index (α) which varied from 0.1 to 0.5 with an average of 0.2.

This is due to inadequate 10m wind speed data, but reinforces the fact that alpha varies temporally and spatially (Table 3.4).

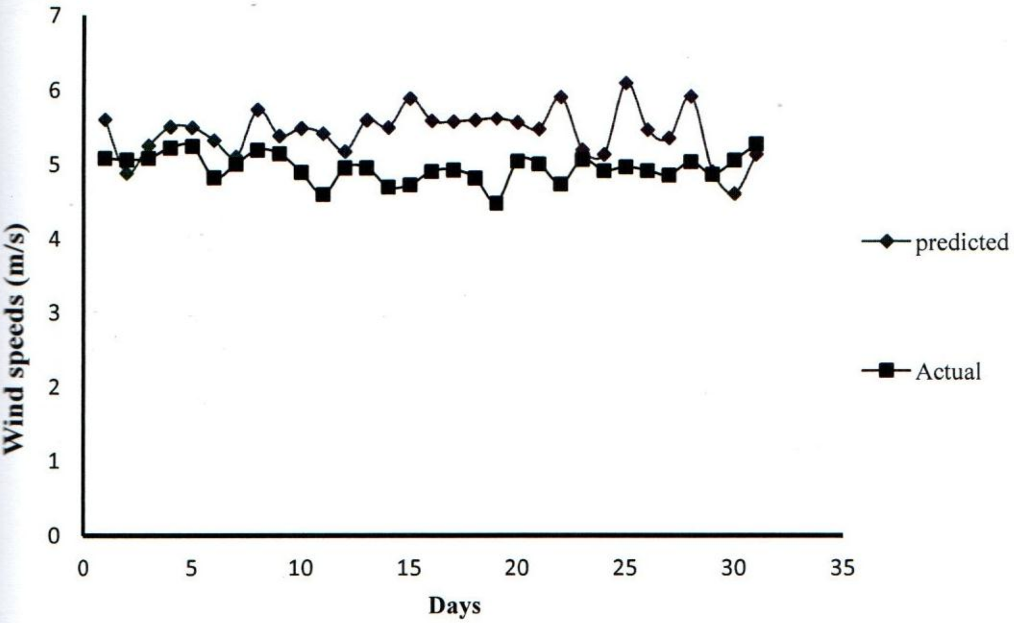


Fig: 3.7: Actual and predicted (α) Generated Wind Speeds for Kisumu, (2006-2011).

Additionally, the Weibull parameters in Table A 3.7 in the appendix were used to predict data at the 2m for each of the LS stations to higher heights as shown in Table 3.4 below, (also in Figures B3.12 and Table A3.9 in the appendix) (% increase of wind speeds) in appendix. Figures B3.13 in the appendix correspondingly show wind power distribution for a turbine of 6.1 m diameter. The aim was to find a suitable procedure of estimating wind speeds potential at 10m height for water pumping wind mill or electricity generation for the LS.

Table:3.3:Average seasonal 10m actual vs. predicted wind speeds (2009-2011)Kisumu

	Dec-Mar		Apr-July		Aug –Nov		Annual	
Day	**Pred**	**Actual**	**Pred**	**Actual**	**Pred**	**Actual**	**Pred**	**Actual**
1	5.95	6.39	4.66	4.33	6.2	4.57	5.61	5.09
2	5.38	5.67	4.43	4.52	4.89	5.02	4.89	5.07
3	5.75	5.99	4.85	4.57	5.18	4.7	5.26	5.09
4	5.83	5.51	5.67	4.8	5.06	5.4	5.51	5.23
5	6.44	5.71	5.18	4.61	4.84	5.42	5.5	5.25
6	5.97	6	4.23	4.17	5.83	4.34	5.33	4.83
7	6.17	6.09	4.04	3.97	5.08	4.98	5.11	5.01
8	6.28	5.88	5.51	5.17	5.47	4.55	5.74	5.2
9	6.4	5.88	4.91	4.56	4.89	5.01	5.39	5.15
10	5.81	5.51	5.1	4.33	5.54	4.85	5.49	4.9
11	5.86	5.04	4.7	4.01	5.7	4.74	5.42	4.6
12	5.33	5.5	4.84	4.3	5.42	5.09	5.18	4.96
13	6.58	5.23	4.9	4.7	5.33	4.96	5.6	4.96
14	7.06	5.25	5.02	4.32	4.51	4.53	5.5	4.7
15	6.86	5.9	5.69	4.17	5.19	4.11	5.89	4.73
16	6.16	5.39	5	4.06	5.6	5.27	5.59	4.91
17	6.05	5.6	4.77	4.14	5.92	5.05	5.58	4.93
18	6.83	4.98	4.27	4.4	5.77	5.09	5.6	4.82
19	6.46	4.74	5.04	4.3	5.36	4.4	5.62	4.48
20	6.86	5.09	4.92	5.02	4.95	5.03	5.57	5.05
21	6.26	5.52	5.55	4.43	4.66	5.09	5.48	5.01
22	6.88	5.29	5.48	4	5.37	4.94	5.91	4.74
23	5.92	5.24	4.65	4.2	5.06	5.77	5.2	5.07
24	5.87	5.7	4.33	3.71	5.22	5.35	5.14	4.92
25	6.38	5.66	6.97	4.14	5.16	5.1	6.1	4.97
26	5.98	5.97	5.36	4.05	5.12	4.74	5.47	4.92
27	5.85	5.84	4.83	3.94	5.4	4.79	5.36	4.86
28	6.67	5.77	5.37	3.94	5.72	5.41	5.92	5.04
29	5.07	6.09	4.44	3.89	5.23	4.63	4.91	4.87
30	4.72	5.99	4.45	4.06	4.72	5.13	4.61	5.06
31	5.69	6.66	4.69	3.99	5.03	5.18	5.14	5.28
Avg	**6.11**	**5.65**	**4.96**	**4.28**	**5.27**	**4.94**	**5.44**	**4.96**

Table 3.4: 2m and 10m predicted Wind Speeds Based on α for Lake Shore Stations

	Ahero		Muhuru		Rusinga		Kibos (m/s)		Kadenge		Kisumu		Kisumu		Ksm-Ob
	2m	**10m**	**2m**	**10m**	**2m**	**10m**	**2m**	**10m**	**2m**	**10m**	**2m**	**10m**	**2m**	**10m**	**10m**
[illegible]	0.9	1.8	2.3	4.2	2.9	5.1	0.9	1.7	1.6	3.1	2	3.3	1.5	2.8	5.70
[illegible]	1	1.9	2.2	3.7	2.8	4.7	0.9	1.8	1.3	2.4	2.1	3.5	1.7	3.2	6.30
[illegible]	2.6	5	2.8	5.2	3.1	5	1	1.9	1.6	3.1	2	3.5	1.8	3.3	5.90
[illegible]	0.8	1.6	2.1	3.7	2.2	3.9	0.8	1.6	1.2	2.3	1.2	2	1.6	2.5	4.90
[illegible]	0.7	1.3	2.3	4.4	2.2	4.1	0.6	1.3	1.1	2.2	0.6	1.1	1.1	2.3	4.20
[illegible]	0.7	1.6	2.2	4.1	2.1	3.5	0.6	1.2	1	2.2	0.5	1	1.1	2.1	4.30
[illegible]	0.7	1.6	2.4	4.4	2.2	3.8	0.7	1.4	1.2	2.5	0.8	1.5	1.5	3	4.20
[illegible]	0.7	1.5	2.7	5.3	2.6	4.4	0.3	0.7	1.2	2.5	1	1.9	1.5	2.9	4.20
[illegible]	1.4	2.8	2.9	4.9	2.5	4.8	0.5	0.9	1.4	2.8	1.3	2.6	1.4	2.8	5.20
[illegible]	0.9	1.7	2.8	4.7	2.7	4.9	0.8	1.8	1.3	2.3	1.2	2.3	1.4	2.7	5.00
[illegible]	0.7	1.4	2.6	4.7	2.7	4.6	0.8	1.6	1.2	2.4	1.1	2.2	1.5	3	4.60
[illegible]	0.9	1.8	2.7	5	2.8	4.6	0.7	1.4	1.3	2.6	1.5	2.7	1.6	3	5.30
	1.0	2.0	2.5	4.5	2.6	4.5	0.7	1.4	1.3	2.5	1.3	2.3	1.5	2.8	5.70

Ob= observed.

The two approaches show that the determined alpha is consistent with the location of the site and hence can be used in estimating wind speed from 2m to 10m within the LS. That within a certain radius a ratio can be used. Most notable is that relationship of 2m and 10m vary with location (Refer to table 3.1 for distance relationships)

Also, data of any one year for a particular month on an hourly basis was noted (as in section [illegible].3.1) as adequate to predict wind speed with height for a particular station within the LS, *with 95% confidence level which is sufficiently accurate especially where there is lack of data.* This means one year record is a good estimate or precursor to many years, which is useful for confirmation of trend.

Table 3.4 further shows the monthly wind speeds as at 2m and the projected wind speeds to 10 m height from the Weibull α determination. The ratio of weibull generated V_{10} to actual V_2 is derived as shown in Fig 3.8, Rusinga being 1.74, Muhuru 1.81, Kisumu1.88, Kadenge 1.98, Kibos 1.99 and Ahero at the highest ratio of 2.03. But for Kisumu the ratio of observed data at 2m and 10 m is higher, being 3.8, though the pattern is consistent with the alpha generated wind speeds at 10 m. This difference in ratio for Kisumu may be attributed to the anemometer types, the 2m being mechanical while the 10m is digital type. It was observed that these ratios also vary with distance and speed from Lake Shore (Fig 3.8). Muhuru and Rusinga with higher wind speeds are nearest to the Lake water while Kadenge, Kibos and Ahero with lower wind speeds are furthest.

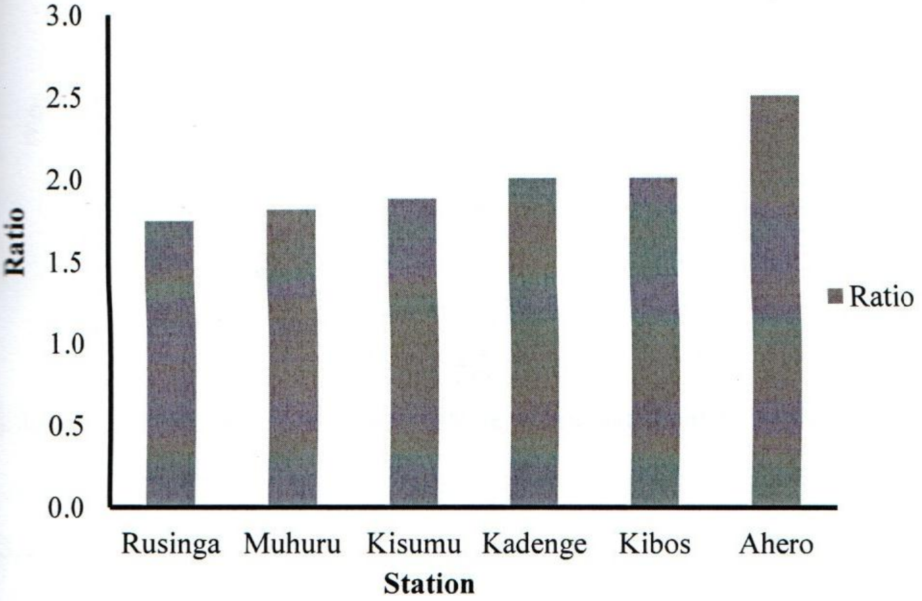


Fig: 3. 8: **LS Ratio of Wind Speeds at 2m to 10 m Projection**

Simple regression equations (as in Figure B3 14 in the appendix) were hence developed based on actual data available from the stations Kisumu and Rusinga. The wind speeds of 2 m and 10 m were found to obey linear and quadratic relationship for both the stations. The monthly averages for Kisumu as in Figure 3.9 also fit a quadratic relationship for data of 2m and 10m for the record period 2006 to 2011. Fig B3.14 in the appendix further illustrates equations for both Rusinga and Kisumu (actual data). The graphs 1 to 2 are for Rusinga, 3 and 4 are for Kisumu while 5 and 6 are for Kisumu actual 2 m wind speeds regressed against the calculated alpha derived 10 m wind speeds. A look at Fig B3.14 in the appendix shows that the linear graphs tend to start at origin and progress at an angle for all the two stations. This is correct as zero wind means no wind and no rotation. Note; that the minimum cut in speed is machine-dependent.

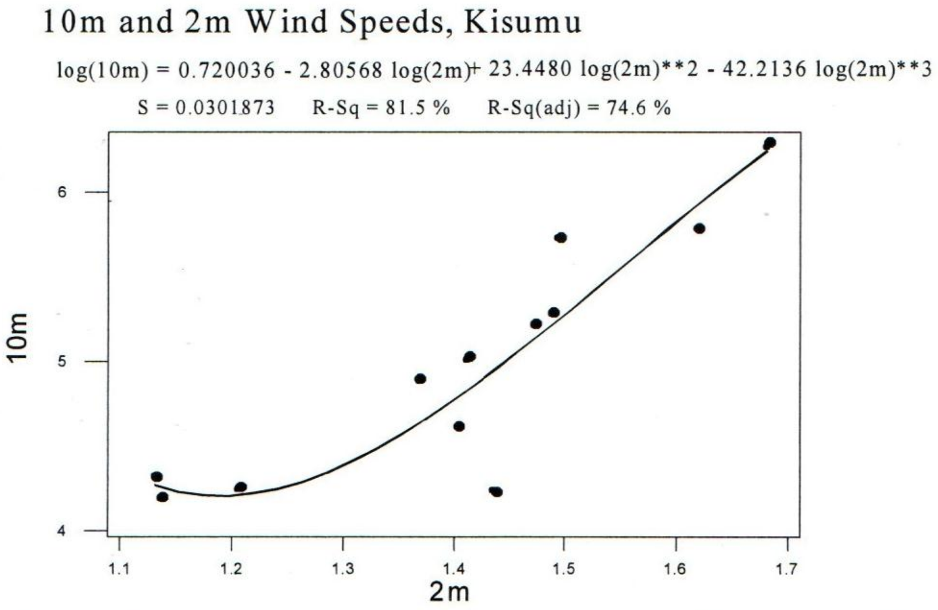


Fig: 3.9: **Monthly Relationship between 2m and 10m Wind Speeds-Kisumu (2006-2011)**

3.4.3.3 Wind Speed Variation with Location

The different sites within the Lake Shore show variation of wind speeds with location. A common factor (α) that change with site represents attributes of the stations from the water line. The variation could be due to topography that increases frictional resistance to the flow of wind. The result shown in the Figure 3.10 is a negative linear relation of wind speed and wind speed law index (alpha) based on location. The Fig 3.10 is a plot of average wind speed from a location based on; average of daily data from December to March denoted as quarter one (Q1) or the dry period of the year. Table 3.5 and A3.12 in the appendix further illustrates the variation of the wind speed law index by LS station and month of the year for both direct and indirect as is determined. The Law index allows use of equation 3.4, and ratios may be used within a radius of a data capture station because of the consistencies observed.

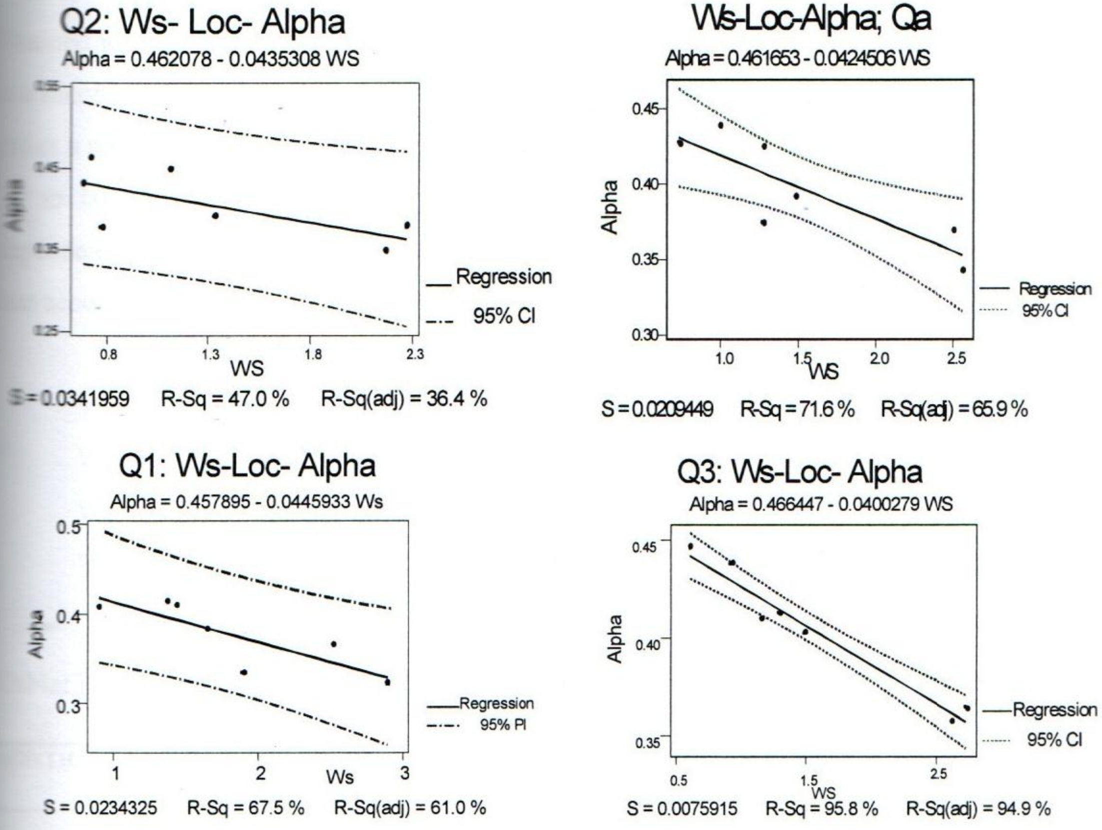


Fig: 3.10: Wind Speed Location Relationship for Lake Shore (LS) stations.

Note that above the regression line from right to left (or upwards) are stations Rusinga, Kadenge, and Kibos. Likewise below the regression line or equal to, from right to left are Muhuru, Kisumu (03), Kisumu (04) and Ahero.

The wind speeds – alpha index relationship showed high correlation respectively for Q3, Annual (Q_A), Q1 and Q2 being least and moderate. This indicates there was variation of strength of relationship of wind speeds –with seasons, when monthly wind speeds and was regressed and compared (annual, dry, wet, short rain periods). From Fig 3.8 (Kadenge & Kisumu); (Kibos & Ahero) and (Rusinga & Muhuru) had different average wind speeds at different sections of the graph, similar to variation with height of the station as in section 3.4.2. Kisumu was represented by two years 1996 and 2004 Figure 3.10which were also close together in the regression graph area, confirming the wind speeds were of the particular location. The other stations were represented by the year 1996. The regression relationships obtained were as below for Q1, Q2, Q3 and QA (equations 3.11 to 3.14). It is clear that alpha is a function of wind speed strength and the characteristics of the area. The power law index (α) as a relationship estimate therefore can be used to estimate the wind speeds potential from 2m to 10m for the LS case as it is location specific, wind speed dependent and period dependent. The equations can therefore be used for a location but time period must be taken into account.

$\mathrm{WS} = 22\alpha - 10$…………………… Dec to March ……..……………………...... (3.11)

$\mathrm{WS} = 23\alpha - 11$…………………..… April to July ……………………………… (3.12)

$\mathrm{WS} = 25\alpha - 12$…………………… August to November……… ……………. (3.13)

$\mathrm{WS} = 24\alpha - 11$ ………………...… Annual winds speed……...……………….. (3.14)

Table:3.5: Values of the determined alpha index α for the LS Stations/locations

MONTH	**Ahero 95**	**Muhuru 95**	**Rusinga 95**	**Kibos 95**	**Kadenge 95**	**Kisumu 96**	**Kisumu 04**	**LS avg**	**Kisumu 2006-08**	
									Actual	**Predicted**
January	0.44	0.37	0.35	0.40	0.43	0.33	0.38	**0.39**	**0.76**	**0.35**
February	0.38	0.31	0.34	0.43	0.38	0.32	0.40	**0.37**	**0.84**	**0.36**
March	0.40	0.39	0.29	0.42	0.39	0.33	0.36	**0.37**	**0.85**	**0.35**
April	0.45	0.35	0.34	0.44	0.43	0.33	0.30	**0.38**	**0.82**	**0.32**
May	0.42	0.41	0.39	0.42	0.42	0.39	0.43	**0.41**	**0.85**	**0.41**
June	0.51	0.38	0.32	0.43	0.48	0.42	0.42	**0.42**	**0.85**	**0.42**
July	0.48	0.38	0.33	0.44	0.47	0.38	0.41	**0.41**	**0.87**	**0.4**
August	0.45	0.41	0.31	0.52	0.44	0.39	0.39	**0.42**	**0.79**	**0.39**
September	0.42	0.34	0.41	0.37	0.45	0.44	0.41	**0.41**	**0.81**	**0.42**
October	0.44	0.33	0.38	0.47	0.34	0.41	0.38	**0.39**	**0.81**	**0.39**
November	0.44	0.38	0.33	0.41	0.42	0.41	0.43	**0.40**	**0.82**	**0.42**
December	0.43	0.39	0.31	0.38	0.43	0.36	0.39	**0.39**	**0.76**	**0.38**
Avg	0.44	0.37	0.34	0.43	0.42	0.37	0.39	**0.40**	**0.82**	**0.38**

3.5 Conclusion and Recommendation

The wind resource is variable within the lake shore by site, time; height of measurement and by distance from the shore line The characteristics were consistent (daily, monthly, seasonal and direction and Weibull derived alphas)and this constitute the calm, land breeze, and sea breeze sessions within the 24 hour period. This can be attributed to temperature change on land and lake water surfaces. These imply that the wind speeds does vary within the LS with comparable similarity. But the frequency tables from which the wind directions are constructed show that the predominant wind speeds are in the range of 2-4 m/s at 2 to 10m height, which is consistent according the wind direction charts. The three parameter Weibull distribution gave a good account of wind speeds at 2m and that the location (ε) parameter tables A 3.7,3.8 and figure B 3.11 in the appendix is a necessity to show on a linear scale the duration (start and the end) of wind speeds and strength (magnitudes) for a given site. It was found that without the location parameter (by use of scale and shape parameters only) the point of start of wind speeds is not identifiable. And this does not give adequate details on duration and strength of the wind speeds. Monthly data gave reasonable estimate for wind speed prediction for the 2m to 10m. The hourly data or shorter time step is good for determining the wind speed strength and duration compared to daily records. The wind speed strength from the cube power equation and duration is important for water pumping design systems.

The power law index α was determined from equation 3.4 and the Weibull distribution (equation 3.5) and used directly with equation 3.8, proposed by Justus and Mikhail (1976a). This gave a good account of the wind patterns as is in figure 3.12 and thus a method for estimating wind speeds from 2 m to 10 m. But this avoided the route of random generation of wind speeds by the Weibull parameters from known height to the unknown which gave none responsive results, which could also be explored Predicted and actual wind speeds by use of power law index (α) for Kisumu station gave good relationships for dry, wet, moderate and annual data R^2 = (0.54, 0.66, 0.66, 0.83) respectively. Equation 3.4 in section 3.2.1 is for wind speeds alpha relationship at the LS is for now proposed to be $\frac{V_B}{V_A} = \left(\frac{Z_B}{Z_A}\right)^{0.8}$. Should alpha be Weibull calculated, from 2m wind speeds at the LS then it be multiplied by 2.

A relationship ratio of wind speeds at a location for two heights showed linearity (figures 3.8 and 3.10) towards the inland from near the lake shore. The ratio relationship can be used as a method in the same respect for estimating wind speeds at 10m from 2m at the LS. It is observable from figures 3.8 and 3.10 the three site categories, that wind speeds decreased as one moves inland. Wind speeds are highest at the shore (Muhuru and Rusinga), moderate for Kisumu and Kadenge and lowest inland for Kibos and Ahero.

A Known (α) value at a location will allow estimation of wind speed at higher height. That the developed equations (3.11 to 3.14) for example, $WS = 2.38\alpha - 1.1$ show that the (α) index has a negative relation with location. It is higher for low wind speeds and similar in trend with the ratio relationship. These equations are therefore variable with wind speeds strength; period and location, hence α is location based and a method for estimating wind speeds for two heights at a location. For Kisumu station, the Weibull determined alpha (α) was half the actual (Average of 0.4 and 0.8). The linear, quadratic and cubic relationship of 2m and 10m wind speeds was established. Just like α index, on their own, the equations may not be universally applied but they can be used within a radius or locality and for comparisons of site wind speed behavior.

Kisumu data can be used to represent the whole of Lake Shore even with variations.

3.5.2 Recommendations

And the approaches and equations developed are reasonable and usable within the limits of data. But there is need within the LS to improve on data capture in terms of equipment, intensity and extent. At present the work is limited to 10m and further research should be for use of the equations and methods beyond 10m, taking into account the location, direction, diurnal and the seasonal variation.

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APPENDIX

ation Approaches to Weibull Parameters.

Maximum Likelihood

$$k = \left\{\frac{\sum_{j=1}^{n} v_i^k ln(v_i)}{\sum_{j=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} ln(v_i)}{n}\right\}^{-1} \text{.......}(3.15)$$

$$c = \left(\frac{i}{n}\sum_{i=1}^{n} v_i^k\right)^{1/k} \text{.......}(3.16)$$

Moments – Weibull: The moments of the Weibull distribution can be calculated from the parameters as shown below:

Mean: $\in +c\Gamma\left(1+\frac{1}{k}\right)$ ....(3.17)

Standard Deviation: $\sqrt{\Gamma}\left(1+\frac{2}{k}\right)-\left(\Gamma\left(1+\frac{2}{k}\right)\right)^2$ ....(3.18)

Skewness:

$$\frac{\Gamma\left(1+\frac{3}{k}\right)-3\Gamma\left(1+\frac{2}{k}\right)\Gamma\left(1+\frac{1}{k}\right)+2\Gamma\left(\Gamma\left(1+\frac{1}{k}\right)\right)^3}{\left(\Gamma\left(1+\frac{2}{k}\right)-\left(\Gamma\left(1+\frac{1}{k}\right)\right)^2\right)^{3/2}} \text{.......}(3.19)$$

Kurtosis: $\frac{\Gamma\left(1+\frac{4}{k}\right)-(\ \ )4\Gamma\left(1+\frac{3}{k}\right)\Gamma\left(1+\frac{1}{k}\right)+6\Gamma\left(1+\frac{2}{k}\right)-\left(\Gamma\left(1+\frac{1}{k}\right)\right)^2-3\Gamma\left(\left(1+\frac{1}{k}\right)\right)^4}{\left(\Gamma\left(1+\frac{2}{k}\right)-\left(\Gamma\left(1+\frac{1}{k}\right)\right)^2\right)^2}$ ....(3.20)

$$f(v|\varepsilon ck) = \begin{cases} 0 & v <= \varepsilon \\ \frac{\eta}{\sigma}\left(\frac{v-\varepsilon}{c}\right)^{k-1} e^{-\left(\frac{v-\varepsilon}{c}\right)^k} & x > \varepsilon \end{cases} \text{.......}(3.21)$$

Parameters: location: ε $-\infty < \varepsilon < \infty$,

Scale: c $c > 0$

and

Shape: k $k > 0$

[illegible] A3.6:Seasonal Annual Diurnal Wind Speed Variation for (Kisumu and Kadenge)

[illegible]	Annual Av	1st Dry (m/s)	Wet	Moderately Wet
[illegible]	1.9	2.03	1.76	1.9
[illegible]	1.83	2.04	1.6	1.85
[illegible]	1.83	2.08	1.42	2.01
[illegible]	2.25	2.44	1.98	2.34
[illegible]	2.2	2.18	2.11	2.31
[illegible]	2.45	1.9	2.62	2.85
[illegible]	4.04	3.67	4.02	4.41
[illegible]	3.94	4.04	3.72	4.05
[illegible]	5.12	5.93	4.08	5.36
[illegible]	7.23	8.41	5.86	7.42
[illegible]	9.02	10.36	7.51	9.18
[illegible]	10.45	11.98	9.01	10.37
[illegible]	10.85	12.54	9.52	10.49
[illegible]	10.67	12.83	9.11	10.06
[illegible]	10.39	12.7	8.69	9.78
[illegible]	9.09	11.34	7.66	8.27
[illegible]	6.97	8.45	6.28	6.19
[illegible]	5.15	5.91	4.68	4.86
[illegible]	4.21	4.78	3.94	3.92
[illegible]	3.33	3.55	3.14	3.3
[illegible]	2.55	2.98	2.18	2.51
[illegible]	2.51	2.89	2.18	2.45
[illegible]	1.97	2.22	1.68	2.02
[illegible]	1.73	1.88	1.48	1.83
	5.07	**5.8**	**4.43**	**4.99**

Table:A3.7: Location, Scale & Shape Parameters for LS Stations (Average: 1996-2011)

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
[illegible]												
ε	0.543	0.266	0.321	0.437	0.17	0.549	0.534	0.413	0.945	0.49	0.348	0.49
c	0.386	0.029	0.651	0.374	0.947	0.163	0.235	0.36	0.517	0.41	0.382	0.437
k	2.638	3,645	4.014	2.216	3.602	1.642	2.063	2.063	2.713	2.29	2.129	2.934
[illegible]												
ε	-565	0.366	0.428	0.924	1.747	-2.85	1.604	2.264	1.535	1.338	1.724	1.73
c	3.409	2.053	2.445	1.337	0.561	5.18	0.933	0.613	1.465	1.584	0.933	0.77
k	10.3	4.169	6.271	3.776	1.161	15.66	2.349	1.444	3.731	3.776	1.862	2.638
[illegible]												
ε	1.746	1.39	0.641	0.966	1.499	0.315	0.799	0.765	1.923	1.871	1.224	0.835
c	1.341	1.53	2.696	1.412	0.77	1.906	1.581	2.613	0.613	0.93	1.639	2.112
k	2.994	1.774	4.634	2.453	2.542	5.192	3.292	1.244	1.244	1.762	2.848	4.634
[illegible]												
ε	0.314	-0.526	0.513	0.314	0.139	0.151	0.321	0.487		0.583		-7.908
c	0.667	1.614	0.521	0.423	0.545	0.471	0.404	0.196		0.27		9.262
k	3.645	6.836	0.987	3.088	5.192	4.331	4.334	1.51		1.751		11.98
Kadenge												
ε	1.166	0.533	0.976	0.762	0.628	0.32	0.994	0.895	1.06	-0.04	0.753	0.891
c	0.446	0.342	0.759	0.462	0.492	0.244	0.272	0.357	0.351	1.463	0.525	0.432
k	1.546	2.271	1.915	1.836	3.561	1.537	1.349	1.751	1.786	5.873	1.774	2.002
Kisumu 96												
ε	0.306	0.41	0.583	0.384	-0.13	0.058	-0.23	-0.24	0.904	0.676	0.587	-0.408
c	4.786	1.838	1.622	1.703	0.782	0.539	0.921	0.78	0.429	0.611	0.606	1.651
k	5,270	4.45	3.121	4.277	3.442	2.29	3.442	4.634	2.163	2.017	2.112	9.185
Kisumu-94												
ε	0.754	1.03	99.52	-0.663	0.723	0.605	-0.57	0.854	0.926	0.618	1.109	-15.98
c	0.868	0.705	97.23	2.402	0-477	0.524	2.077	0.78	0.567	0.913	0.444	17.6
k	3.52	1.211	198	5.78	2.129	2.163	8.101	2.29	3.096	4.064	1.612	93.16

Where: ε = Location, c = Scale and k = Shape

able:A3.8: Weibull Distribution Descriptive Statistics of LS Stations.

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
hero												
N	31	28	30	30	31	30	31	31	30	31	30	31
Mean speed	0.886	1.013	0.911	0.768	0.663	0.695	0.743	0.733	1.405	0.853	0.686	0.924
SD	0.14	228	0.165	-0.158	0.152	0.091	0.106	0.137	0.183	0.168	0.167	0.161
Skewness	0.3	-0.01	-0.09	0.5	0	0.92	0.59	0.36	0.27	-0.46	0.55	0.19
Kurtosis	-83	0.91	-0.17	-0.89	0.9	1.34	1.61	0.29	-0.66	-0.77	-0.30	-0.25
P-valu	0.607	0.404	0.979	0.4429	0.3478	0.28	0.442	6503	0.873	0.758	0.95765	0.98
huru												
Mean	2.682	2.242	2.702	2.132	2.279	2.151	2.431	2.82	2.857	2.769	2.553	2.414
SD	0.38	0.504	0.423	0.357	0.46	0.418	0.374	0.391	0.395	0.423	.0.462	0.279
Skewness	-0.65	-0.12	-0.4	-0.4	1.6	-0.78	0.43	1.14	-0.03	-0.04	0.73	0.3
Kurtosis	93	-0.63	0.76	0.15	3.33	1.48	-0.23	2.5	-0.5	-0.85	0.18	-0.66
P-value	0.176	0.802	0.587	0.7888	0.4143	0.747	0.907	0.202	0.926	0.551	0.653	0.8
singa												
Mean	2.944	2.75	3.105	2.218	2.182	2.068	2.217	2.624	2.494	2.699	2.684	2.766
SD	0.436	0.793	0.605	0.545	0.288	0.388	0.474	0.52	0.462	0.485	0.556	0.474
Skewness	0.17	0.8	-20	0.38	0.34	-0.28	0.08	-0.09	1.44	0.81	0.22	-1.2
Kurtosis	-0.38	1.86	1.25	0.3	0.47	-0.51	0.48	0.32	2.95	0.58		0.13
P-value	0.967	0.281.8	0.308	0.4679	0.6791	0.75	0.574	0.751	0.183	0.879	0.158	0.913
[illegible]												
Mean	0.917	0.982	0.975	0.692	0.641	0.583	0.689	0.663	0.789	0.797	0.797	0.967
SD	0.184	0.259	0.243	0.134	0.111	0.102	0.096	0.119	0.148	0.126	0.126	0.19
Skewness	-0.01	-0.45	0.64	0.14	-0.28	-0.23	-0.15	1.06	-0.58	-0.2	-0.2	-0.71
Kurtosis	3.72	0.27	1.71	0.99	0.35	0.82	-0.75	2.33	2	0.22	0.22	2.8
P-value	0.014	0.898	0.118	0.2564	0.7983	0.491	0.645	0.049	0.696	0.849	0.849	0.066
dienge												
Mean	1.567	1.284	1.649	1.173	1.071	1.04	1.194	1.239	1.373	1.315	1.22	1.274
SD	0.265	0.348	0.366	0.232	0.138	0.146	0.187	0.203	0.181	0.268	0.272	0.2
Skewness	1.02	0.47	0.69	0.75	0.01	1.03	1.27	0.82	0.79	-0.36	0.8	0.63
Kurtosis	1.51	0.16	0.44	1.18	-0.11	1.19	3.32	0.38	0.6	0.14	0.31	-0.08
P-value	0.191	0.906	0.537	0.2932	0.0043	0.779	0.218	0.801	0.7	0.997	0.903	0.976
umu-94												
Mean	1.951	2.086	2.034	1.165	0.571	0.535	-0.596	1.00	1.284	1.218	1.123	1.517
SD	0.359	0.427	0.509	0.409	0.226	0.04	0.266	0.175	0.185	0.281	1.267	0.204
Skewness	-0.29	-0.17	0.13	-0.14	0.04	-0.02	0.04	-0.2	0.53	0.62	0.56	-0.6
Kurtosis	-0.38	0.23	-0.22	-1.12	0.13	-0.15	-0.02	-0.28	-0.03	1.13	-0.26	0.62
P-value	0.313	0.684	0.987	0.1292	0.8378	0.919	0.92	0.993	0.766	0.524	0.937	0.997
umu-03												
Mean	1.535	1.692	2.006	1.561	1.146	1.069	1.384	1.545	1.432	1.446	1.507	1.522
SD	0.246	0.549	0.634	0.446	1.209	0.226	0.287	0.32	0.181	0.229	0.253	0.227
Skewness	0.02	1.5	-1.17	-35	0.55	53	-0.54	0.46	0.15	-0.1	0.95	-1.08
Kurtosis	-0.26	2.78	0.52	2.16	0.99	0.01	1.11	0	-0.98	0.151	1.09	1.89
P-value	0.976	0.315	0.899	363	0.5153	0.907	0.925	0.827	0.255		0.683	0.389

Table:A3.9: % Increase of Wind Speeds with Height and Location

	Ahero-10m	Muhuru-10m	Rusinga-10m	Kibos-10m	Kadenge-10m	Kisumu-10m	Kisumu-10m
uary	104	81	75	91	101	69	85
ruary	86	66	72	99	85	68	89
rch	91	87	60	97	88	71	80
ril	105	75	74	102	100	70	63
ay	95	95	87	96	98	87	99
ne	127	83	67	99	116	96	97
ly	117	83	71	103	113	83	95
gust	106	93	66	132	104	87	87
ptember	97	73	93	83	107	101	95
ctober	103	71	83	113	73	93	83
vember	104	83	71	95	96	93	101
cember	98	87	65	85	101	78	88
ean	**103**	**81**	**74**	**99**	**98**	**83**	**88**

Table:A3.10: P-Value for Fit of Weibull Distribution for Kisumu 2m wind speeds

Month	1996	1997	1998	1999	2000	2001	2002	2003
Jan	0.86	0.87	0.24	0.73	0.49	0.31	0.98	0.29
Feb	0.90	0.87	0.58	0.88	0.88	0.69	0.91	0.60
Mar	0.94	0.70	0.78	0.05	0.40	1.00	0.98	0.60
Apr	0.05	0.66			0.96	0.13	0.25	0.62
May	0.50	0.76	1.00	0.95	0.99	0.84	0.73	0.77
Jun	0.37	0.51	0.91	0.11	0.98	0.92		0.88
Jul	0.57	0.99	0.70	0.97	0.61	0.92	0.42	0.16
Aug	0.42		0.32	0.80	0.96	0.99	0.94	0.56
Sep	0.20	0.96	0.96	0.78	0.44	0.66	0.50	0.99
Oct	0.77	0.97		0.96	0.63	0.52	0.98	0.35
Nov	0.61	0.92	0.22	0.65	0.91	0.91	0.97	0.33
Dec	0.91	0.82	0.80	0.03	0.04	0.89	0.98	0.30
Month	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Jan	0.40	0.97	0.94	0.97	0.82	0.85	0.98	0.97
Feb	0.99	0.84	0.80	0.85	0.27	0.78	0.31	0.76
Mar	0.68	0.46	0.85	0.09	0.65	0.96	0.90	0.59
Apr	0.86	0.86	0.93	0.48	0.34		0.04	0.85
May	0.09	0.48	0.94	0.79	0.83		0.48	0.89
Jun	1.00	0.69	0.91	0.97	0.87	0.85	0.95	0.98
Jul	0.99	0.40	0.80	0.47	0.98	0.03	0.93	0.77
Aug	0.77	0.37	0.79	0.98	0.78	0.08	0.81	0.52
Sep	0.92	0.38	0.97	0.07	0.89	0.84	0.27	0.70
Oct	0.53	0.64	0.22	0.98	0.98	0.22	0.15	0.52
Nov	0.94	0.83	0.75	0.99	0.79	0.35	0.72	0.21
Dec		0.71	0.47	0.84	0.47	0.37	0.49	0.76

Table:A 3.11: Descriptive (wind speeds) Statistics of Kisumu Station

Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	N	31	31	30	31	29	31	31	31	31	27	31	31	31	31	31	31
Jan	Mean	1.681	1.461	1.318	1.81	1.36	1.951	1.429	1.728	1.524	1.064	1.656	1.472	1.6	1.786	1.54	1.68
Jan	SD	0.346	0.275	0.294	0.229	0.39	0.359	0.257	0.292	0.232	0.178	0.275	0.172	0.4	0.407	0.25	0.35
Jan	Skewness	-0.078	0.711	-0.52	0.277	0.38	-0.291	-0.458	0.213	-0.17	-0.19	0.216	-0.033	-0.39	-0.27	0.02	-0.08
Jan	Kurtosis	-0.424	0.168	1.784	0.316	0.99	-0.879	-0.014	0.795	-0.88	-0.18	-0.28	0.149	-0.21	0.253	-0.26	-0.42
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Feb	N	28	28	28	28	28	28	28	28	28	28	28	28	27	28	28	28
Feb	Mean	1.64	1.465	1.585	1.951	1.41	2.086	1.453	1.681	1.976	1.215	1.918	1.845	1.61	2.052	1.69	1.82
Feb	SD	0.218	0.262	0.39	0.203	0.29	0.427	0.323	0.209	0.249	0.252	0.386	0.209	0.24	0.357	0.55	0.32
Feb	Skewness	-0.887	0.119	-0.51	0.429	-0.26	-0.166	-0.429	-0.26	-0.65	0.378	1.045	0.767	-0.13	0.593	1.5	-0.28
Feb	Kurtosis	1.55	-0.601	1.194	-0.28	0.28	0.23	-0.347	-0.58	-0.08	0.012	0.659	0.333	-1.05	-0.43	2.79	0.34
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Mar	N	31	31	31	31	31	31	31	30	31	31	31	31	31	21	31	31
Mar	Mean	1.68	1.635	1.28	1.948	1.61	2.034	1.521	1.471	1.989	1.369	1.731	1.715	1.89	1.754	2.01	1.81
Mar	SD	0.389	0.261	0.224	0.474	0.25	0.509	0.293	0.293	0.338	0.269	0.377	0.245	0.4	0.302	0.63	0.28
Mar	Skewness	0.215	-0.421	-0.88	-0.06	0.71	0.134	-0.08	-0.36	-1.16	0.541	0.507	-0.32	0.14	0.013	-1.17	-0.09
Mar	Kurtosis	0.004	-0.649	1.106	-1.28	1.36	-0.218	-0.234	0.643	2.648	0.189	-0.63	2.016	0.24	-0.33	0.52	0.3
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Apr	N	30	30			30	30	27	30	30	29	30	30	30		30	30
Apr	Mean	1.246	1.209			1.49	1.165	1.424	1.342	1.478	1.117	1.222	1.455	1.46		1.56	1.53
Apr	SD	0.408	0.31			0.26	0.409	0.289	0.189	0.337	0.303	0.336	0.287	0.28		0.45	0.3
Apr	Skewness	0.977	0.259			0.49	-0.14	-0.45	0.374	0.217	-0.13	0.185	0.055	0.54		-0.35	0.89
Apr	Kurtosis	3.521	0.335			-0.45	-1.12	0.693	0.678	-0.1	-0.59	-0.61	0.57	1.31		3.16	0.29
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
May	N	31	31	30	31	31	31	31	31	30	30	31	31	31		31	31
May	Mean	1.096	1.013	1.288	1.201	1.16	0.571	1.181	1.249	1.042	0.958	1.024	1.285	1.24		1.15	1.26
May	SD	0.194	0.226	0.201	0.183	0.21	0.226	0.229	0.205	0.237	0.168	0.193	0.201	0.13		0.21	0.19
May	Skewness	0.042	0.371	-0.41	0.247	0.11	0.043	0.552	-0.21	-0.5	0.845	0.011	0.038	-0.11		0.55	0.2
May	Kurtosis	0.398	0.401	-0.06	-0.28	-0.32	0.129	0.269	-0.59	2.946	0.431	-0.1	0.211	-0.61		0.99	-0.69
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jun	N	28	26	27	28	28	28		28	28	28	27	28	28	17	28	28
Jun	Mean	1.205	1.037	1.307	1.19	1.04	0.532		1.128	1.085	0.945	1.085	1.372	1.28	1.257	1.06	1.28
Jun	SD	0.248	0.191	0.238	0.299	0.16	0.228		0.236	0.137	0.183	0.184	0.172	0.15	0.278	0.23	0.21
Jun	Skewness	0.489	-0.038	0.455	1.181	0	0.499		0.459	-0.43	0.628	0.415	0.245	0.47	-0.45	0.68	0.52
Jun	Kurtosis	0.759	0.551	-0.55	3.102	-0.49	-0.29		-0.29	0.481	0.299	0.451	0.425	-0.39	0.8	0.2	-0.1
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jul	N	31	31	31	31	31	30	30	31	31	31	31	31	31	31	31	31
Jul	Mean	1.289	1.176	1.577	1.12	1.29	0.596	1.167	1.096	1.237	0.931	1.266	1.516	1.47	1.494	1.38	1.58
Jul	SD	0.287	0.196	0.258	0.242	0.23	0.266	0.265	0.225	0.204	0.243	0.187	0.313	0.23	0.285	0.29	0.27
Jul	Skewness	0.553	-0.366	0.861	0.092	0.22	0.042	-0.105	-0.44	0.249	0.684	-0.05	0.416	0.2	0.392	-0.54	0.8
Jul	Kurtosis	-0.583	-0.162	0.856	-0.18	0.54	-0.021	0.858	1.826	-0.42	1.685	-0.61	0.473	-0.05	2.992	1.11	0.41
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Aug	N	31		31	30	31	31	31	31	31	31	31	31	31	31	31	31
Aug	Mean	1.302		1.616	1.514	1.48	1	1.369	1.631	1.432	1.213	1.373	1.624	1.44	1.506	1.55	1.57
Aug	SD	0.221		0.224	0.273	0.26	0.175	0.279	0.282	0.287	0.176	0.208	0.226	0.35	0.225	0.32	0.25
Aug	Skewness	0.713		0.005	1.001	-0.4	-0.199	0.461	0.047	0.694	0.755	-0.26	0.409	0.01	-0.44	0.46	-0.94
Aug	Kurtosis	1.524		-1.01	0.346	-0.27	-0.278	0.061	0.518	-0.34	1.571	-0.56	-0.099	0.03	-0.86	0.0007	2.84
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Sep	N	30	30	29	30	30	30	28	30	30	30	30	30	30	30	30	30
Sep	Mean	1.316	1.364	1.584	1.606	1.47	1.284	1.364	1.606	1.532	1.419	1.311	1.583	1.43	1.514	1.43	1.5
Sep	SD	0.235	0.2	0.246	0.287	0.25	0.185	0.223	0.196	0.223	0.248	0.26	0.34	0.24	0.168	0.18	0.24
Sep	Skewness	0.25	0.331	0.707	-0.24	0.31	0.529	1.287	0.262	-0.24	1.071	0.443	0.123	0.44	0.076	0.15	-1.11
Sep	Kurtosis	1.249	0.268	-0.23	0.404	0.72	-0.031	1.817	-0.59	-0.32	2.157	-0.21	2.023	0	0.049	-0.98	0.48
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Oct	N	31	31		31	31	31	31	31	31	31	31	30	31	31	31	31
Oct	Mean	1.234	1.194		1.423	1.46	1.218	1.284	1.498	1.354	1.426	1.29	1.607	1.42	1.529	1.45	1.34
Oct	SD	0.248	0.221		0.368	0.26	0.282	0.257	0.208	0.227	0.307	0.253	0.204	0.22	0.202	0.23	0.21
Oct	Skewness	0.635	-0.076		-0.14	0.68	0.624	-0.117	0.612	0.281	0.185	-1	-0.144	0	-0.67	-0.1	0.5
Oct	Kurtosis	0.405	-0.459		-0.45	0.72	1.128	-0.379	1.244	0.7	0.332	4.096	-0.164	-0.42	2.464	-1.1	0.48
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Nov	N	29	29	29	28	28	29	29	29	29	29	29	29	29	29	29	28
Nov	Mean	1.201	1.348	1.6	1.224	1.42	1.134	1.239	1.353	1.161	1.457	1.273	1.597	1.39	1.521	1.5	1.35
Nov	SD	0.222	0.221	0.26	0.157	0.2	0.265	0.227	0.232	0.193	0.188	0.23	0.296	0.2	0.264	0.26	0.21
Nov	Skewness	0.076	-0.998	0.536	-0.73	0.45	0.527	0.106	1.045	0.117	0.561	0.248	-0.135	0.71	-0.07	0.98	-0.26
Nov	Kurtosis	0.554	1.883	1.855	1.091	-0.21	-0.234	-0.2	1.812	-0.56	-0.03	-0.56	-0.223	0.28	-0.97	1.04	-1.04
Month	Parameter	1995	1996	1997	1998	1999	2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
Dec	N	30	30	29	30	29	30	30	30		30	30	30	30	30	30	30
Dec	Mean	1.434	1.326	1.704	1.728	1.6	1.093	1.508	1.348		1.759	1.294	1.704	1.62	1.38	1.52	1.58
Dec	SD	0.169	0.359	0.232	0.334	0.36	0.324	0.299	0.169		0.249	0.265	0.225	0.29	0.274	0.23	0.26
Dec	Skewness	0.906	-0.557	0.245	0.132	0.02	-1.702	-0.158	0.59		0.034	1.213	0.18	-0.01	-0.02	-1.05	0.33
Dec	Kurtosis	0.329	-0.441	0.161	-1.43	-1.34	3.255	-0.349	0.695		-0.72	1.879	-0.003	0.72	-0.95	1.72	-0.69

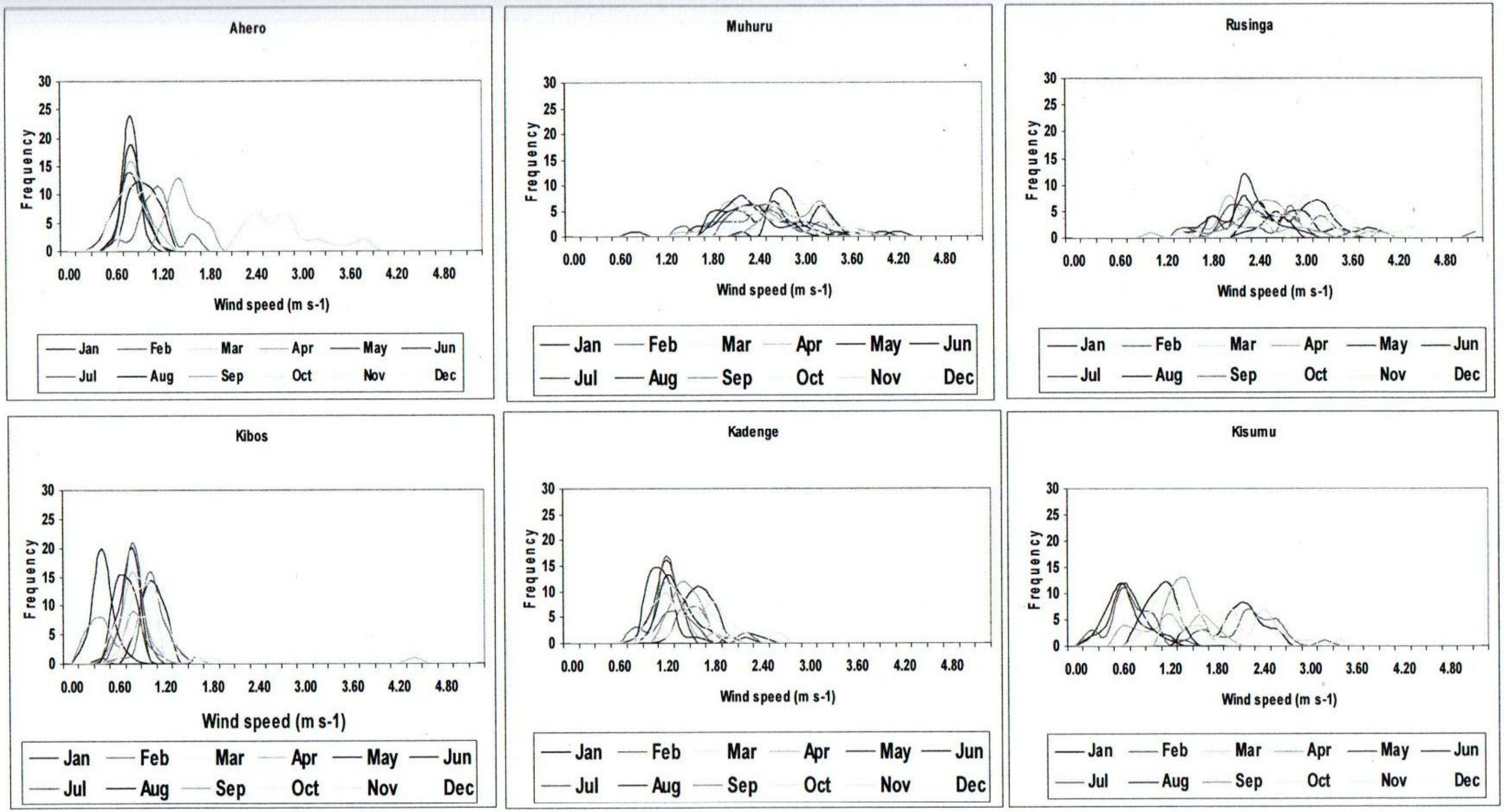
Table:A 3.12: Seasonal daily Alphas for 1996-2011 at 10m Wind speeds.

Date	Q1(December-March)	Q2(April-July)	Q3(Aug-November)	(Annual)
1	0.78	0.83	0.79	0.80
2	0.74	0.79	0.77	0.76
3	0.80	0.83	0.79	0.81
4	0.80	0.87	0.81	0.82
5	0.84	0.86	0.74	0.82
6	0.80	0.80	0.87	0.82
7	0.81	0.73	0.77	0.78
8	0.82	0.89	0.84	0.85
9	0.82	0.84	0.79	0.81
10	0.79	0.89	0.85	0.84
11	0.79	0.83	0.85	0.82
12	0.73	0.82	0.81	0.78
13	0.86	0.82	0.82	0.84
14	0.89	0.85	0.73	0.82
15	0.87	0.92	0.78	0.86
16	0.82	0.86	0.81	0.83
17	0.81	0.84	0.86	0.83
18	0.85	0.76	0.83	0.82
19	0.84	0.86	0.82	0.84
20	0.85	0.81	0.75	0.81
21	0.83	0.90	0.73	0.82
22	0.87	0.92	0.84	0.88
23	0.78	0.82	0.77	0.79
24	0.84	0.78	0.79	0.81
25	0.84	0.93	0.79	0.85
26	0.78	0.87	0.78	0.81
27	0.80	0.85	0.80	0.81
28	0.85	0.91	0.85	0.87
29	0.74	0.82	0.82	0.79
30	0.72	0.79	0.75	0.75
31	0.81	0.80	0.77	0.80
Avg.	0.81	0.84	0.80	0.82

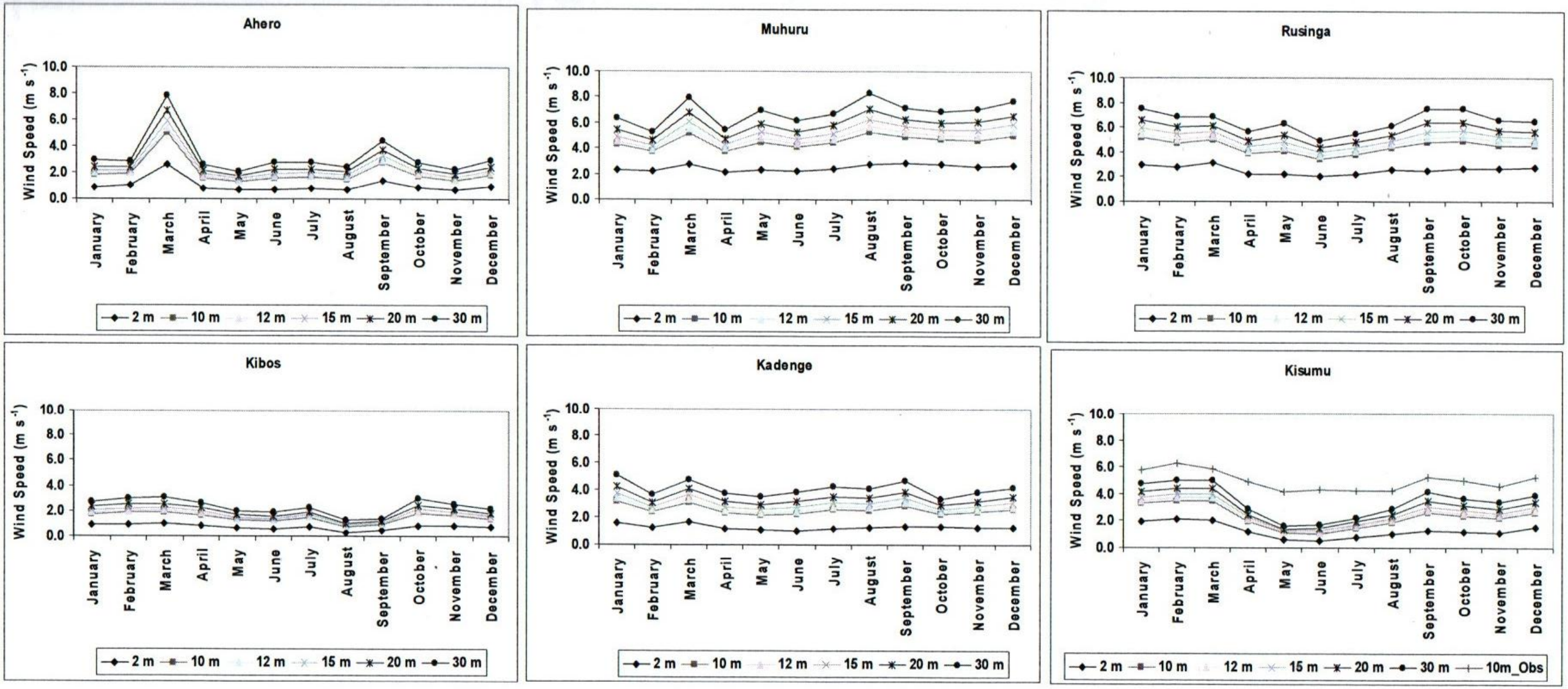
Table:A 3.13: Alpha Index for Different Conditions

Location	Alpha
Unstable air above open water surface:	0.06
Neutral air above open water surface:	0.10
Unstable air above flat open coast:	0.11
Neutral air above flat open coast:	0.16
Stable air above open water surface:	0.27
Unstable air above human inhabited areas:	0.27
Neutral air above human inhabited areas:	0.34
Stable air above flat open coast:	0.40
Stable air above human inhabited areas:	0.60

Source: Kaltschmitt *et al* (2007)



ig: B 3.11: Weibull Distribution for the LS Stations



ig: B 3.12: LS Wind Speed Height Increase based on Weibull Parameters of 3aheight determination.

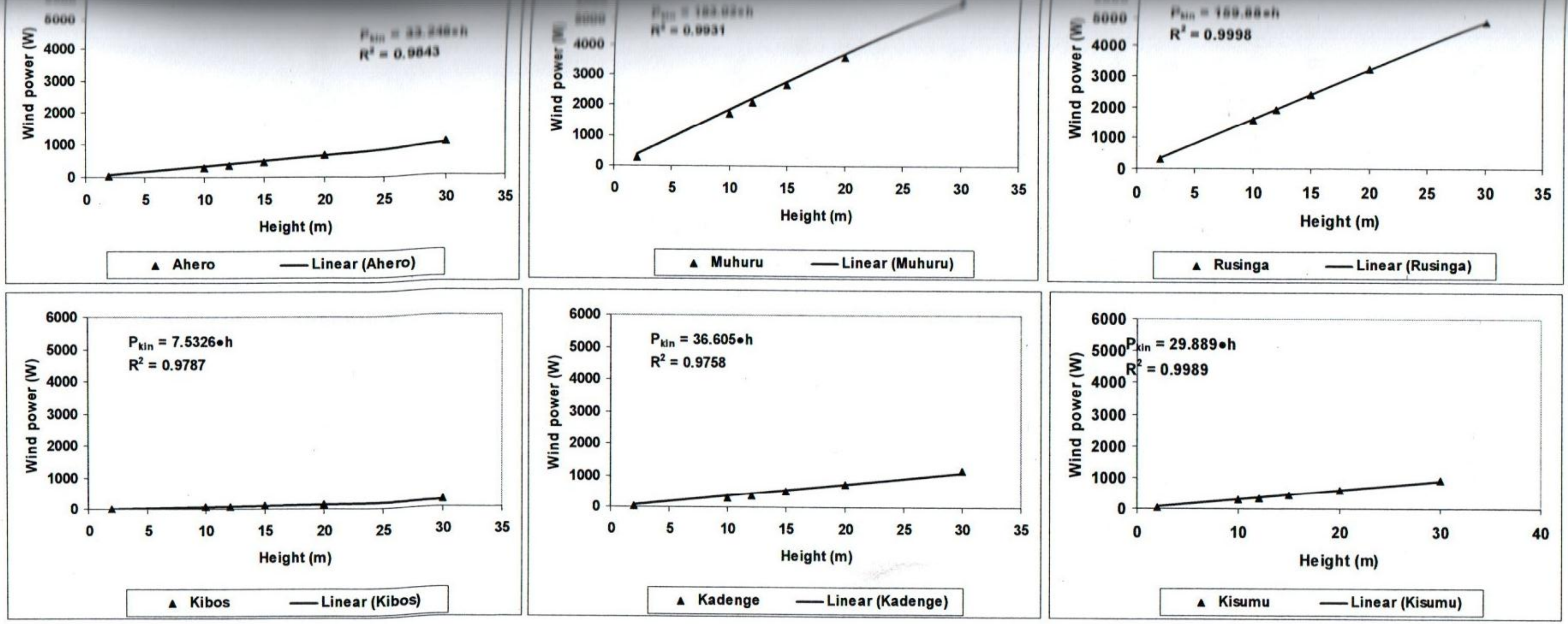
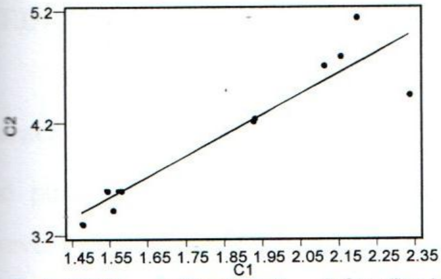


Fig.B3.13 Wind Energy Power potential with Height for 6 LS Stations.

Relationship of ActualRusinga 2m and 10m Wind speed

C2 = 0.683286 + 1.84417 C1

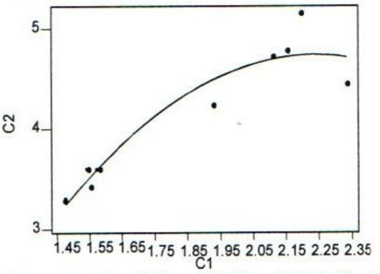


1

S = 0.257668 R-Sq = 86.5 % R-Sq(adj) = 84.8 %

Relationship of ActualRusinga 2m and 10m Wind speeds

C2 = -8.16455 + 11.5337 C1 - 2.57714 C1**2

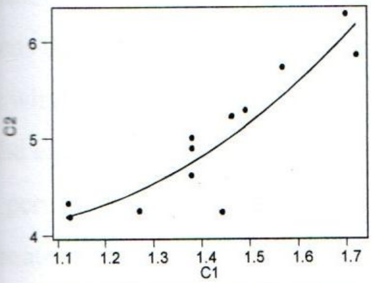


2

S = 0.221925 R-Sq = 91.2 % R-Sq(adj) = 88.7 %

Relationship of Actual (Kisumu)2 m and 10 m Wind speeds

S = 0.326804 R-Sq = 82.5 % R-Sq(adj) = 78.6 %

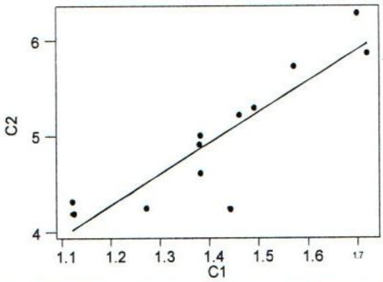


3

C2 = 7.23149 - 6.61489 C1 + 3.49009 C1**2

Relationship of Actual(Kisumu) 2m and 10m Wind Speeds

C2 = 0.366769 + 3.25830 C1

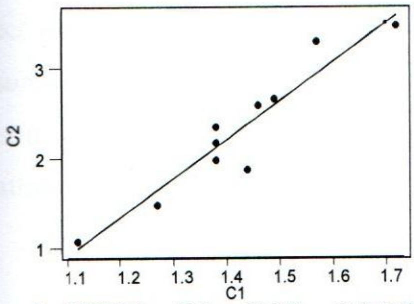


4

S = 0.343168 R-Sq = 78.5 % R-Sq(adj) = 76.4 %

Relationship of 2m and 10m Weibull Wind Speeds (Kisumu)

C2 = -3.85316 + 4.32843 C1

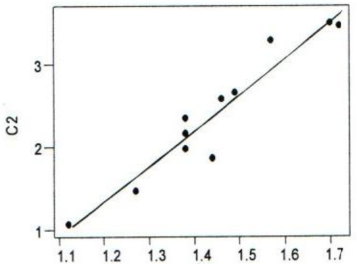


5

S = 0.229770 R-Sq = 93.5 % R-Sq(adj) = 92.8 %

Relationship of 2m and 10m Weibull Wind Speeds (Kisumu)

C2 = -3.23201 + 3.43506 C1 + 0.315797 C1**2



6

S = 0.241793 R-Sq = 93.5 % R-Sq(adj) = 92.1 %

Fig: B3.14: Relationship of 2 m and 10 m Wind Speeds for LS Stations- Kisumu and Rusinga

CHAPTER FOUR

PREDICTION OF WIND PUMP WATER DISCHARGES FOR DRIP IRRIGATION AT THE SHORES OF LAKE VICTORIA- KENYA

Abstract

Wind pump discharge has traditionally been estimated from the manufacturer's tables. However for wind pump drip irrigation (WPDI) system there is need to relate the discharge to hydraulics in the pipeline, emitter discharges and weather/soil. The relations in the form of governing equations comprise of the instantaneous discharge, pipe and emitter and resource equations (ET_0, area and duration of irrigation). The objective was to predict from the wind speeds the expected discharge and relate it to the governing equations. The actual wind speed and wind pump discharge data from Rusinga was initially used to compare the performance of the existing instantaneous equations. The Kisumu 10 m wind speeds assisted in developing the percent availability instantaneous discharge equation($Q = K(\sum V_i R_i)$which was used to estimate the irrigation depth and area. The results showed that the irrigation duration could be predicted from the developed wind speed interval percent availability tables. The discharge equation (model) developed based on availability was in agreement with the results from the existing instantaneous wind pump discharge equations. The accuracy of the equations to predict discharge improved with the length of the hourly wind speed, short time step of measurements, the startup pump rotation speed and the measuring equipment. It was possible to estimate wind pump discharge from hourly wind speeds, wind strength limits thus irrigation area, depth and duration.

on

n the horizontal axis wind pumps is often presented in graphs or charts by number of model equations 4.1 to 4.5 by LE Gourièrês (1982), Lysen l Chemelil (2001) are in use. Lysen (1982) matches windmills to the wind phical, computational and the estimation methods. Continued research in rge relationships however is still necessary due to variations in locations on nd types of wind mills and pumps. Drip irrigation is an added relationship xis wind pumps, the wind speeds, and for even the modern state of art low s. Previous works in drip irrigation and wind power are found in Kabok 2), Kabok and Chemelil, (2005), Ale and Pradhan (2006).They noted that e used to drive drip irrigation systems.

nping Windmill

ng windmill (WPWM) with a horizontal axis consists of a rotor pivoted ver for proper orientation to the wind and multi-blade coupled to a on pump. The design incorporates the rotor on the tripod coupled to the udes a safety mechanism. The system is for water delivery. The basic wind rotor design have been outlined by Wilson *et al.,* (1976), Lysen (1982), Van Dam (2010). The WPWM may be taken as a black box with wind as the output.

rbines should be designed to maximize the use of the slowest wind speeds operate at the rated wind speed or power output (Van Dam, 2010). Wind by wind energy converters (WECs) should operate over a rising limb from esign rated speed until the WEC is furled out (Ahmet, 1995).

perate in an air stream and experience lift (perpendicular to the direction of eam) and drag (in the direction of undisturbed air flow) forces which can dimensionless quantities. Factors that affect the Betz's power coefficient num power fraction of extracted wind power) are the rotation of the wake (due to the extra kinetic energy losses), the finite number of blades, air lip losses) and the drag and lift coefficients ratio (C_d/C_L) which does not adius (R) of the rotor for the water pumping windmill is chosen based on y output (E) as: $E = 0.1R^2V^3T$ where; V_d is design wind speed, T is time length in hours in which average wind speed was taken, R is the radius of the rotor. The use of the average wind speed is an assumption since variation of wind speeds cannot be ignored. The other methods for estimating the energy are described by Lysen (1982); including graphical, computational and estimation approaches. These are not adequate for planning wind pump drip irrigation (WPDI) system, due to the need for an assessment of wind speed availability in duration and strength.

b) Wind Pump Drip Irrigation Discharge Estimate

The wind pump discharge for any turbine or pump is normally provided by the manufacturers as in Table 4.1, the table shows performance in terms of the head of water for different wind pump rotor diameters, for the model, for varied wind speeds and the discharges as the output. This approach assumes magnitudes of time length, wind strength and duration of wind speeds at a location. The effect of wind speed variation with time in the day and season is not taken care of (masked). It emphasizes variation of discharge with distance at a location much more. This needs investigation. A worthy assumption with regard to this is that the recorded data points over a particular hour (9 am or 10 am) for a long period can be representative of what happens in every second within the hour; presumably to depict the fluctuation of the wind speeds within the hour. Thus, this was the basis of percent discharge model development. Ale and Pradhan (2006) provide an insight into use of wind pumps for irrigation but does not fully and directly show how WPDI is used with the variations of wind speeds. It is possible to use a horizontal axis wind pump for drip-irrigation as long as key aspects are determined or taken care of in the design process (Kabok 2001; Kabok and Chemelil, 2005). These include identification and quantification of performance characteristics of the wind pump (expected discharge versus the head), wind regime at the proposed site and the type of emitter to be used. In addition, the normal irrigation design parameters of evapotraspiration, soil and water characteristics referred to as the climate resources (Ogindo, 2003), should be determined for the design process. WPDI technology can be applicable to arid and semi-arid lands (ASAL) and other areas faced with harsh dry weather conditions but have favorable wind regimes for crop production.

c) Hydraulic Equations

The hydraulic equations 4.1 to 4.5 are herein grouped into categories as; Emitter and Hazen Williams equation, Instantaneous Discharge Equations and climate resource equations as shown below. Although they were developed separately, they require to be linked for the better understanding of wind pump irrigation. Apart from the development of linkage frame work, the instantaneous discharge equations need review and assessment due to variation of variation of wind pump models/sizes and wind speeds.

Group A: Emitter and Hazen Williams equation; could be crosschecked by Darcys or Scobeys equations and are stated as;

$$q_e = K_e H^x \ldots\ldots (4.1)$$

$$\mathrm{J} = \frac{\Delta \mathrm{H}}{\mathrm{L}} \times 100 = 1.13 \times 10^{11} \frac{\mathrm{Q}^{1.85}}{\mathrm{C}} \mathrm{D}^{4.87} \mathrm{F} \ldots\ldots (4.2)$$

Group B: The Instantaneous Discharge Equations

$$Q_s = \frac{0.1 A V^3}{\rho H} \quad \text{(Lysen, 1982)} \ldots\ldots (4.3)$$

$$Q_s = \frac{0.1 D^2 V^3}{H} \quad \text{\{LE Gourieres, 1982);} \ldots\ldots (4.4)$$

$$Q_s = K V_{(Foot\ of\ wind\ pump)} \quad \text{(Kabok and Chemelil, 2001)} \ldots\ldots (4.5)$$

where $K = {}^{A}/_{\rho}$, A = Rotor area; ρ is air density for equation 4.5

Group C; The emitter and climate resource equations, to be related to the best of equations 4.3 - 4.5, are as below:

$$\text{design emitter discharge:} q_d = \frac{I_{Rg} \times A_p}{I_h} \ldots\ldots (4.6)$$

$$\text{System discharge: } q_s = \frac{I_i \times A_t \times I_{Rg} \times 10}{I_h} \ldots\ldots (4.7)$$

$$I_{Rg} = E_{TCROP}. K_r. E_a + L_r - R \ldots\ldots (4.8)$$

and

$$I_{Rg} = (F_e - w_p) \times d(C_v) m \times R_z \times \frac{P}{100} \times \gamma_b \ldots\ldots (4.9)$$

where; Q = discharge and Q_s = System Discharge, q_e= Emitter Discharge; J = Head Loss in Percent of Pipe; V = Wind Speed Velocity; H = Pressure Head of Operation; D = Pipe Diameter in (mm);

ρ = Density in kg/m^3; F = Pipe Frictional Factor; K, x,K_r & K_e= Constants; L = Length in meters; C = Pipe Friction Coefficient; ΔH = Head Loss in Pipe; q_d = Design Emitter

Discharge; I_i =Irrigation Interval; I_h = Irrigation Hours; A_p= Plant Irrigated Area; A_t = Total Area of Irrigation within the Interval; L_r, = Extra Water Needed for Leaching; R = Water Received by the Plant from other Sources other than Irrigation; IR_g = Maximum Amount or Depth of Water to be Applied (taking into account suitable reduction as all the soil is not Wetted); F= friction F_c = Volume Moisture at Field Capacity (%); d_m = Moisture Depletion Allowed or Desired (%); R_z = Soil Depth or Root Zone in Meters; P = Volume of the Soil Wetted as a Percentage of the Total Volume, γ_b = Bulk Density of the Soil; Wp = wilting point; Ea= System efficiency. Any of equations 4.3 and 4.5 above multiplied by time equals the total volume of water-applied i.e that is. $\sum Q_s t$ = system discharge; and equating to equation 4.7 yields eqn 4.10

$$Q_s I_h = I_t \times A_t \times I_{RG} \times 10 \quad \text{.......} \quad (4.10)$$

This implies,

$$\sum Q_{st} = I_i \times A_t \times I_{RG} \times 10 \quad \text{.......} \quad (4.11)$$

$$R_z = \frac{\sum Q_{st}}{I_i} \times A_t \times \left(F_c - W_p\right) \times 0.1_p \times d_m$$

Equivalent to;

$$R_z = \frac{\sum Q_{st}}{I_i} \times A_t \times S_f \quad \text{.......} \quad (4.12)$$

The manipulation can be done to 4.6 to relate it to emitter discharge. WPDI mode can hence be evaluated from depth of irrigation and emitter discharge.

The objectives of this study at the Lake Shore (LS) were to determine:

1. Percentage usable hourly wind speeds on daily and seasonal basis for water pumping.
2. Wind pump discharges
3. The drip irrigated depth and area.

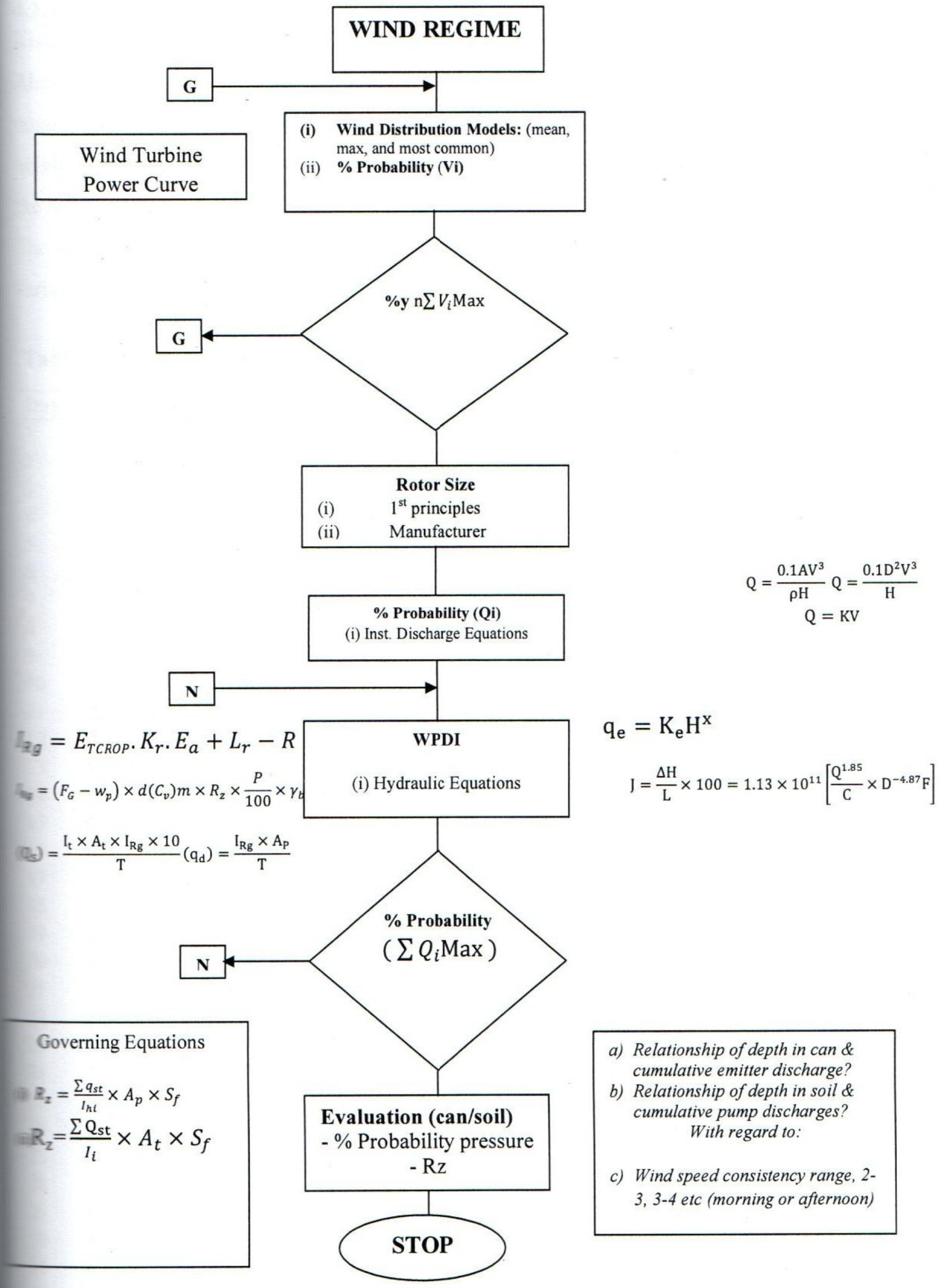


Fig:4.1: **Flow Chart for Design of Wind Pump Drip Irrigation System**

4.2.2 Estimating Hourly Percentage Wind Speeds

Kisumu data was used since the existing other five (Muhuru bay, Kibos cotton, Kadenge, Ahero and Rusinga) stations of the Lake Victoria shore (LS) in Kenya lacked the hourly measured wind speeds records. The hourly wind speeds obtained were measured at 10 m height from the year 1996 to 2011 on a 24 hour day basis using a data logger. Table 4.2 gives the average daily wind speeds and months as shown for Kisumu for the years 2006 to 2011. The table below on magnitude of wind speeds at a glance does not give the details on the variations 24 hour day spectrum.

Table:4.1: Average Daily Wind Speeds for Kisumu (2006 to 2011) 10m height in (m/s)

Day	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1	5.78	6.16	6.69	5.28	3.56	4.10	4.67	3.92	4.63	4.70	4.09	5.52
2	5.36	6.30	6.26	4.49	3.83	4.51	4.39	3.38	4.56	5.89	5.08	4.65
3	5.63	6.47	6.67	5.43	4.95	3.60	4.57	4.66	5.08	4.76	4.32	5.06
4	5.23	6.28	6.08	6.36	4.29	4.83	4.11	4.38	5.03	5.14	5.07	5.15
5	5.22	6.51	6.63	5.57	4.44	4.47	5.16	3.89	5.96	4.79	4.35	5.73
6	6.13	6.19	6.31	5.13	4.31	4.31	3.32	4.57	5.03	5.28	4.38	5.48
7	5.68	6.77	6.83	4.19	3.81	4.04	4.04	3.85	5.52	4.98	4.38	5.35
8	6.51	6.65	5.07	5.59	5.01	5.11	4.42	3.97	4.94	5.08	4.42	6.10
9	5.93	6.67	5.32	5.06	4.46	4.40	4.33	4.76	4.21	4.97	4.95	5.92
10	5.47	5.97	5.81	4.94	4.76	5.39	4.06	4.96	5.07	4.60	5.08	5.38
11	5.81	5.48	5.42	5.08	4.06	3.88	3.53	4.25	5.08	5.81	4.38	4.69
12	5.36	5.66	5.84	4.49	3.92	4.89	3.98	4.12	4.78	5.24	5.01	4.69
13	5.03	5.54	6.53	5.17	3.98	4.35	4.44	4.39	5.79	5.13	4.97	4.69
14	6.44	5.46	5.98	5.10	4.38	4.36	3.54	4.33	4.39	4.12	4.53	4.69
15	6.63	5.96	6.48	5.73	4.09	4.26	4.10	3.91	5.10	4.32	4.38	4.69
16	6.31	5.63	5.76	4.75	3.58	4.53	4.40	4.08	5.70	5.61	4.62	4.69
17	5.70	6.73	5.58	4.76	3.62	3.85	4.22	4.83	5.06	5.03	5.54	4.69
18	5.09	6.32	5.90	4.99	4.24	4.00	4.64	4.38	5.14	5.28	5.41	4.69
19	6.42	5.47	5.17	5.22	3.83	4.06	3.99	3.58	5.42	4.88	4.33	4.69
20	4.94	6.06	5.50	5.16	4.45	4.50	4.15	3.75	5.56	4.84	4.30	4.69
21	5.70	6.02	5.85	5.09	4.11	4.27	5.07	2.61	6.15	5.51	3.83	4.69
22	5.16	6.03	5.66	4.72	4.42	4.44	4.76	5.28	5.23	4.46	4.45	4.69
23	5.21	6.44	5.00	4.24	4.25	4.06	4.14	4.56	6.18	5.43	4.49	4.69
24	5.74	6.36	5.78	4.44	4.26	3.46	3.79	4.38	5.56	5.32	4.78	4.69
25	5.75	6.76	5.47	4.67	4.83	4.72	4.26	4.23	5.66	4.74	4.76	4.69
26	5.76	6.56	5.90	4.59	4.53	4.26	4.28	4.14	5.15	4.67	4.83	4.69
27	5.14	7.08	5.65	4.26	4.03	4.17	4.31	4.22	5.07	4.99	4.22	4.69
28	5.59	8.23	5.23	4.13	4.60	4.25	4.40	4.54	5.48	5.63	4.94	4.69
29	6.07		5.86	4.42	3.44	4.16	4.57	4.84	4.90	4.81	4.06	4.69
30	6.11		5.63	4.05	3.67	4.42	3.83	4.35	5.07	4.57	4.41	4.69
31	6.81		5.80		4.09		3.99	4.26		4.68		4.69
Avg	**5.73**	**6.28**	**5.86**	**4.90**	**4.19**	**4.32**	**4.24**	**4.24**	**5.22**	**5.01**	**4.61**	**4.93**

The frequency distribution of hourly wind speeds recorded over the period of 6 years (2006 to 2011) for Kisumu was used to identify the percent effective wind speed useful for driving the wind pump. The wind speed was segregated with the specific minimum percent contribution to discharge estimates. The speeds were arranged in columns each containing a particular hour (9 a.m, 10 a.m) for the 24 hour wind speed day spectrum. These were further categorized into seasons of four months each; Dec-March (dry period), April-July (wet or long rains) and August-Nov (Short Rains). The frequency of the wind speeds ranges of 1m/s intervals was determined by counts within wind spectrum. The seasonal spectrum or block was further analyzed for each hour for the 24 hour period. This was done by dividing the counts of each wind speed designated intervals by the total number of observations within the particular hour. It was taken as the percentage availability ratio or frequency of each wind speed range within that particular hour. Particularly this was to depict the time periods of similar magnitude, that is, time of the day with consistent strength or magnitude of wind speeds (Low, high and Moderate) when the wind pump is operated to deliver water_for irrigation (8 hrs, 10 hrs, 18 hrs).The ratios as in Tables A4.6 and A4.7 in the appendix allowed observing, detecting and isolating of wind speed ranges with similar magnitudes.

The percent sector spectrum that is responsible for discharge (start rotating speed to design rated speed) needs to be isolated to determine the performance of a wind pump. The continuous pen recorded wind speed data (showing variation within the hour) forms the basic assumption in determining the ratio or percent of the wind speeds spectrum of the hour that actually contributes to the wind mills operational mode (Ahmet, 1995) and thus the wind pump discharge. The wind speed range (chosen interval) just before the cut in speed of rotation and cut out speed of the wind pump will register zero discharge.

The percent wind speeds contributing to discharge were determined based on seasons (the dry, long rains, short rains) and on annual basis Table A4.6 Appendix. This was further grouped based on time period of equal magnitude within the day for the 24 hour period, by choosing time period with similar ratio of wind speed magnitude. The column cell relating to the wind speed intervals were calculated based on the counts divided by the total observations until the values diminished to zero; meaning the ratios could vary depending on the wind speed intervals selected. These ratios showed the strength and magnitude of wind for water delivery and irrigation potential with time.

4.2.3 Prediction of Discharges from Wind Speeds

Measuring wind speed and discharge simultaneously from a wind pump at a point of interest is the sure way of determining the relationship and thus the periodic discharge. The manufacturers often give estimate tables of the performance characteristics of windmills or wind pumps which are often exaggerated and may not be site specific. To estimate (predict) discharge from a wind pump by use of measured hourly wind speeds and the existing instantaneous discharge equations as illustrated in section 4.1b to c.

The amount of water pumped by a wind pump on a daily basis can be estimated based on time of day, season or period of interest. The time with similar ratio or percent wind speed magnitude Table A4.6 in the Appendix was used with the instantaneous equations as is proposed in section 4.1c. For seasons (dry period, wet or long rains or short rains 24 hour); only the season's average ratio per wind speed interval per time period of the day selected. The wind pump equations as proposed in section 4.1c are only instantaneous. The day's cumulative wind pump discharge was estimated by selecting a wind speed mean (V_i) from each day's wind speed range. This was substituted into the chosen instantaneous equation 4.5 as the first step. It was then multiplied by a season's average ratio (R_i) for the hour or the selected hours of the irrigation as the second step. All were then sequentially added from least contributing wind speed range to the maximum and multiplied by the time period of irrigation or hours of need in the day. This gave the total volume of water required for irrigation at that particular time. Taking equation 4.5 in section 4.1c, the expected discharge per seasons average wind speed, based on the selected time period of irrigation, takes the form as below;

$$V_{QT} = KV_{foot\ of\ wind\ pump} \times 3600T \quad \text{.......(4.13)}$$

where;

$$V_{QT} = V_{Q1} + V_{Q2} + V_{Q3} + Vq4 \dots\dots\dots V_{Qn}$$

$$T = 1, 2, 3, \dots\dots\dots\dots\dots\dots\dots 24 \text{ (No. of hours of irrigation)}$$

This implies

$$Q = V_{QT} = 3600K \left(\sum V_i R_i\right) \times T$$

$$Q = K'(\sum V_i R_i) \quad \text{.......(4.14)}$$

where K'=3600KT

Where V_{QT} is the estimated total volume of water discharged by the wind pump, T is the number of hours or time period of irrigation, represented by 1 to n for the 24 hour period, V_i is the selected wind velocity average within the count range, K is a constant; K in equation 4.13 is from the instantaneous equation 4.5. (Kabok and Chemilil, 2001); R_i is the ratio of the range count within the hour.

In order to use equation 4.14 from wind speed data, the percent availability Table A 4.6 in the appendix is first developed as in section 4.2.2. An appropriate instantaneous discharge equation is then selected that should relate to discharge of a particular wind pump. This can be achieved through field or wind tunnel tests just as for the instantaneous equations in section 4.1c. Once the constant k as in equation 4.5 is developed (Kabok and Chemilil, 2001); it can then be used with equation 4.14.

4.2.4 Performance of the Kijito wind pump

Actual wind speeds and discharge from a 6.1m diameter wind pump were taken. The wind pump discharges were measured by an anemometer and an Arad (50 mm discharge) meter. The relationship of the wind speeds by using instantaneous equation 4.5 and results compared with the measured discharges for Kijito wind pump at Rusinga (Tom Mboya School). This was then regressed and a fitted line plot using excel and Minitab software (2000).

The Kisumu hourly 10 m wind speed data were also used to estimate discharges based on the equations 4.3 (Q_1), 4.4 (Q_3), 4.5 (Q_4) based on actual measured discharges and 4.14 (Q_5). The best performing equation compared to Q_4 was selected. Q_5 was developed as in section 4.2.3. The discharge constant K (0.1) for equation 4.13 was adopted from equation 4.4 and as was confirmed during the development of equation 4.5.

4.2.5 Area and Depth of Irrigation

Drip irrigation depth and area is a function of the water supply and other irrigation resources (land, crops, soil and ET_O). The maximum amount or depth of water to be applied (the gross irrigation water requirement IR_g) can then be calculated from Equation 4.8 in section 4.1c which derives its parameters from weather. Reference ET_O was calculated to facilitate the use of equation 4.6 and 4.7 in section 4.1c for determination of the emitter discharge and system charge. The evapotranspiration ET$_O$ influences area and depth of irrigation but its ermination faces challenges since it has not been established for the Lake Shore.

e system discharge was calculated by varying iteratively the parameters of equation 4.7 il pump discharge and irrigation balances were attained compared to the wind pump charge. That is;

stem discharge (q$_s$) equation 4.6.............................. $q_d = \frac{I_{Rg} \times A_p}{I_h}$

Or 4.7.. $q_s = \frac{I_i \times A_t \times I_{Rg} \times 10}{I_h}$

Where;

$$Q_s = q_s = I_t \times A_t \times I_{RG} \times 10 \ldots\ldots \text{(4.15)}$$

This implies,

$$A_t = \frac{Q_s}{I_i \times I_{RG} \times 10} \ldots\ldots \text{(4.16)}$$

And

$$I_{RG} = \quad ET_{CROP}.K_r.E_a + L_r - R \; or \; (F_c - w_p) \times d(C_v)m \times R_z \times \frac{P}{100} \times \gamma_b$$

nce WPDI mode is determined from either system discharge or emitter discharge as ated to the weather. The soil parameters in the Lake Shore can be measured or determined estimated from published data (Linsley, 1979 and; Andriesse and Van der Pouw, 1982) n Table 4.3 below for parameters in equation 4.9.

ble:4.2: Typical Moisture Values for Various Soil Types

	Percentage of Dry Weight of Soil			
oil Type	**Field Capacity**	**Wilting Point**	**Available Water**	**Density (Kg/m^3)**
and	5	2	3	1500
andy Loam	12	5	7	1400
oam	18	10	8	1350
ilt Loam	24	15	9	1300
lay Loam	30	19	11	1300
lay	40	24	16	1200

dopted: Linsley (1979)

The key drip irrigation parameters apart from discharge are ETo with other parameters implied in the gross water requirement (IR_g). The IR_g should be calculated from the weather equation 4.8 or the soil based equation 4.9. The estimated (or determined) discharge can then be used to balance the parameters of equation 4.1 to 4.9.

4.3 Results and Discussion

The Kisumu station had, a cumulative 1800 data points captured at 10 m height for the 6 year time period (1996 to 2011) of which 600 data points are for each of the three seasons (dry, long rains and short rains). A table (A 4.6 in the appendix) was developed to show wind speed intervals (0 to 1, 1.01 to 2, 2.01 to 3, 3.01 to 4), in column one and row one starting from columns 2 to the 25th for each hour of the day (1 to 24 hours). The rest of cell values (row two, column two onwards) apart from the first column were ratios of frequency to the total counts of a wind speed intervals within the hour for the data showing the frequency of wind speeds on the designated wind speed ranges. The developed tables' comprised the wind speed intervals. These were then summarized to constitute Table A 4.6 in the appendix, that showed hourly average ratios (cell values) for the wind speed interval variation on annual and seasonal basis (December-March, April-July, and August-November). This was considered equivalent to frequency as could be derived from a continuously pen recorded data from the particular hour for the wind speed intervals.

However, it is observed that the accuracy of the estimated discharge improves with the length of the hourly measured data (Table A 4.6 in the appendix), the wind speed range step interval and the accuracy of the measuring equipment. The essence of determination of the ratios as in Table 4.4 indicates that estimate calculations can be for the daily discharge on a 24 hour period or can be varied with regard to (Tables A4.6 in the appendix) be specific to the desired time period of irrigation or a season.

4.3.1 Percent usable hourly Wind Speeds

Based on the ratios of the percent wind speeds calculated as in section 4.2.2, the Table 4.4 (extracted from Table A4.6 in the appendix) below in the first column indicates that the hourly wind speeds at Kisumu starts from a wind speed of zero to a maximum of 12 m/s. The rows 1 and 2 in column 1 (.0 to 1 m/s and 1.01 to 2 m/s for example) comprise the wind speed range, which shows that 37%(30+7), 45%, 43% and 41%represents wind speeds availability during the dry, long rains, short rains and annual averages respectively.

he rest of the wind speeds are distributed from 2m/s to 12 m/s, with the usable interval for a nd pump concentrated between 2m/s to 8 m/s. The wind speeds above 8m/s though ailable are low in frequency. Figure 4.2 below represents graphically the spectrum of agnitude of wind for the Kisumu station and the percentage available wind speed per terval.

able:4.3: Usable Wind Speed interval Availability index Kisumu

WS-interval m/s	December-March	April-July	Aug.-November	Annual
1	0.30	0.37	0.36	**0.34**
2	0.07	0.08	0.07	**0.07**
3	0.17	0.18	0.17	**0.17**
4	0.16	0.10	0.10	**0.12**
5	0.11	0.08	0.08	**0.09**
6	0.08	0.08	0.09	**0.09**
7	0.04	0.05	0.06	**0.05**
8	0.03	0.03	0.03	**0.03**
9	0.01	0.01	0.01	**0.01**
10	0.01	0.01	0.01	**0.01**
11	0.00	0.00	0.01	**0.01**
12	**0.00**	**0.00**	**0.00**	**0.00**

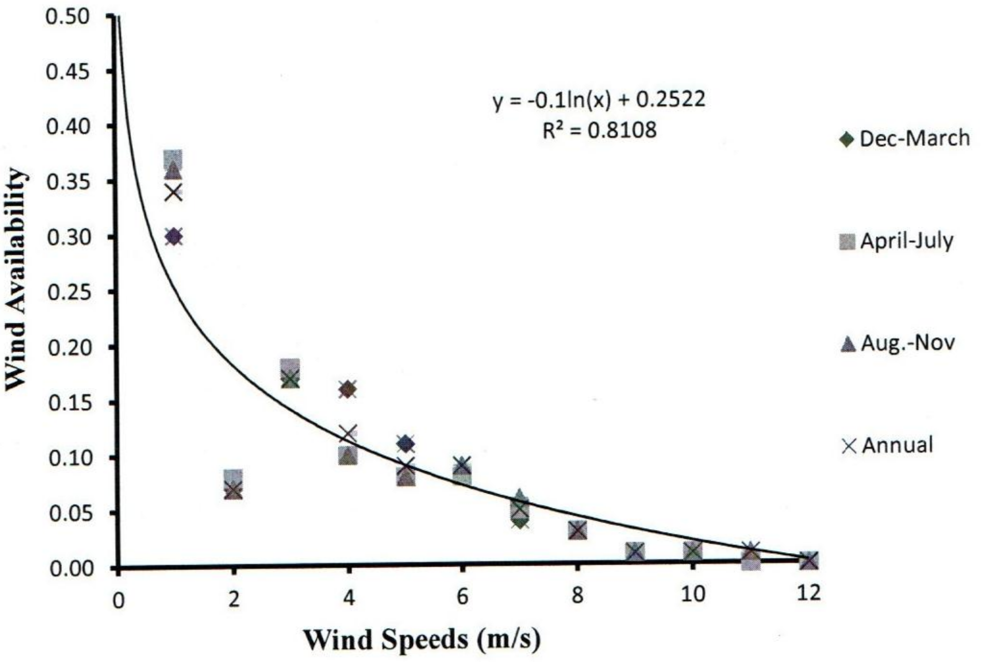


Fig: 4.2: **Percent Availability of Wind Speeds in Kisumu**

Table 4.4 shows the annual maximum and minimum wind speed availability ratios 0.01 to 0.34, respectively. The upper limit ratio (higher wind speeds, 8 -12 m/s) is constant while the lower limit varies with seasons. The wind speeds are higher in the dry season (ratio of 3) compared to the long and the short rain periods (respectively 0.37 and 0.36) of the year. This is an indicator of the minimum and maximum wind speeds available in an area at a particular height, and for calculating the wind pump discharges in a season for time period as desired for irrigation (equation 4.13). The 10 m height hourly frequency distribution (Table 4.4) confirms wind speed variation at Kisumu. The variations are twofold; the percent availability of the wind speed within a season and with the seasons. There is a relationship between the percent of wind speeds within an interval and magnitudes within the season. The relationship is logarithmic having an average trend line equation for availability implying that:

% of a wind speeds in each interval; available

(Dec-March) ....$b_1 = -0.1\ln(x) + 0.25, R^2 = 0.81$

(April-July) ....$b_2 = -0.1\ln(x) + 0.28, R^2 = 0.81$

(Aug-Nov) ....$b_3 = -0.1 ln\,(x) + 0.27,\ R^2 = 0.80$

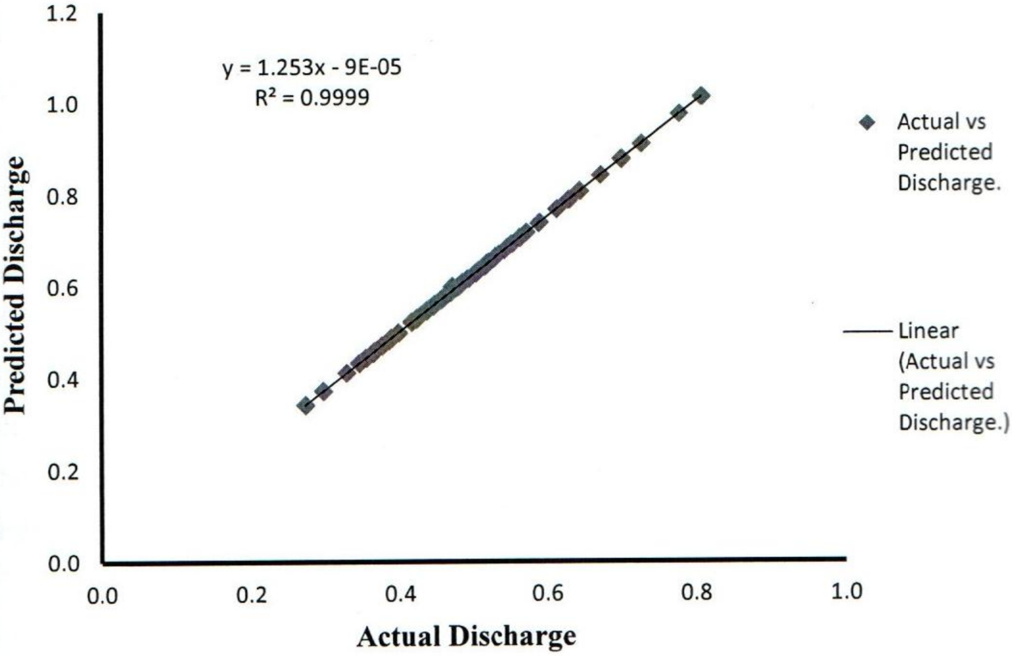
(Annual) ......$b_4 = -0.1 ln\,(x) + 0.26,\ R^2 = 0.81$

where b is the seasonal percent wind speed availability.

This approach of percent wind speed interval availability (Table 4.4), is more informative in comparison with Table 4.1 which is often used by manufacturers in presenting wind pumps' discharges. From table 4.4, the logarithmic relationship shows that during the dry seasons the available wind speeds potential are higher, in that the lower the constants the higher the upper wind speed range availability Table A4.6 and A4.7 in the appendix, these relationships may be due to the temperature effects signified by seasons within the LS The Table A4.6 and A4.7 summarized in Table 4.4 allows the use of equation 4.14 ($Q = K'(\sum V_i R_i)$ developed from instantaneous equation 4.5 to calculate discharges from wind speed intervals though equations 4.3 and 4.4 can also be tested in a similar way. Cumulative discharges per each hour of the day can be calculated as desired from equation 4.4.

2 Predicting Discharge from Wind Speeds

actual and predicted discharge data were compared as shown in Fig 4.4 and from among
three instantaneous equations. Fig 4.4 is an illustration of the work of Kabok and
melil (2005), Q_3 whose equation compared well with the actual discharge Q_4, though
htly higher and to the LE Gourieres equation (1982) Q_2. This is further represented in Fig
for the fit indicating regression equation (Actual = 0.80 Predicted + 0.000072 together
the other regression parameters. The LE Gourieres equation was multiplied by a factor
.001 to make the figure smaller to enable it fit in a graph with the other equations. It
ever bares similarity to the actual, Q_4. Le-Guireres equation compared well at the
inning, but it diverged upwards, showing wind speeds continually increases with
harges. This may not be true because of the rated wind speed and also limit due to
acity and nature of the reciprocating pump.



.4.3: Actual RusingaVs Predicted Q_3 Discharge

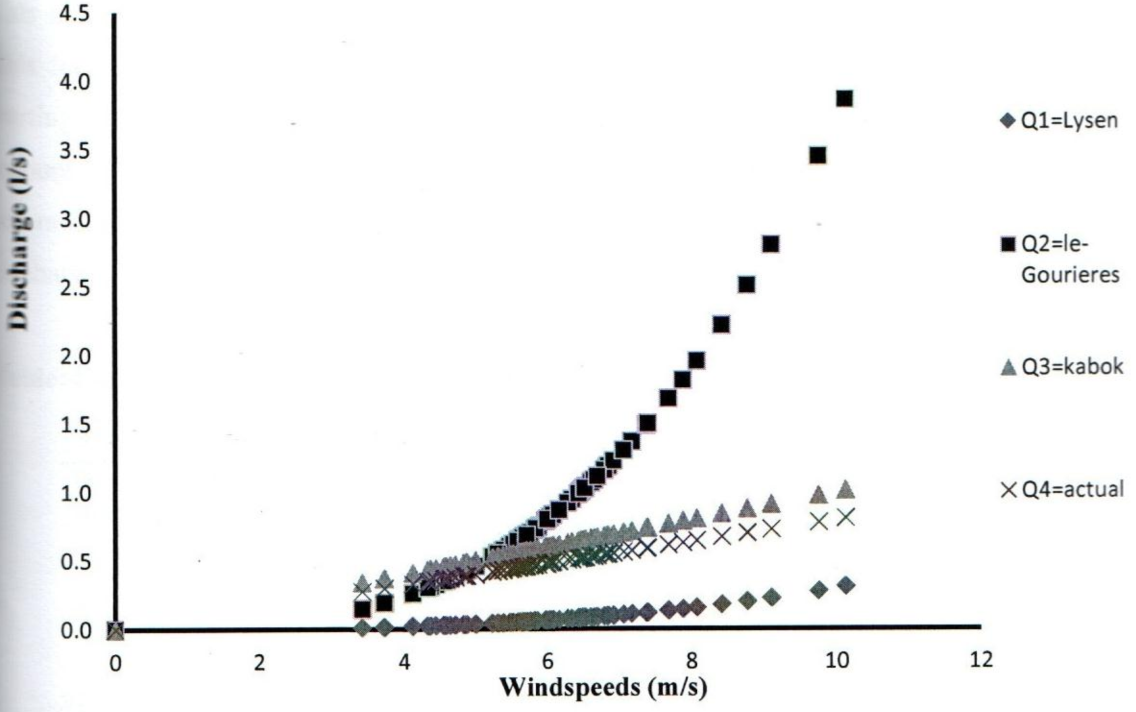


Fig: 4.4: **Predicted Discharge for various Wind speeds**

where; Q1-Lysen, Q2- Le Guireres, Q3-Kabok and Chemelil, Q4 –Actual, Q5-Relate to equation 4.14

In order to use the hourly wind range frequency percentages for determination of discharge of a wind pump, the performance of the equations 4.3 to 4.5 in Fig 4.5 were first determined as in 4.3.2 above. Since Kisumu did not have the measured discharge, values were hence predicted using all the equations as shown in Fig 4.5 with the actual wind speed data in Table 4.2. The seasons wind speed averages (Table 4.2) were then used to determine the expected discharge, including (4.14) Q_5, the percent availability discharge equation.

When Q_3 (Kabok and Chemelil; 2001, 2005) and Q_5 are compared, the seasons estimate discharge is lower by 40% (Q_3 to Q_5) and 25% of the calculated actual discharge (Q_4 to Q_5. These translate respectively to a discharge of 0.72 m^3/ hr and 0.36 m^3/ hr lower. The Kabok and Chemelil (2001, 2005) equation according to Table 4.5 show that the discharge estimate averages 1.78 m^3/ hr; while the new developed equation 4.14 based on the percent availability approach shows discharges averaging 1.1m^3/ hr per season. This is attributed to Q_5 taking into consideration only the usable wind speeds range.

This is reasonable since Fig 4.4 shows that Q_2 is slightly higher than actual discharge Q_4. This though may highly depend on the range of wind speed chosen and the wind pump starting speed selected. The approach indicates that output is comparable as long as the amount of data is large enough (> 5 years) and wind pump starting speed is correctly determined from field tests. Hence the method can be used as a first estimate of the expected discharge.

Table:4.4: Estimated Seasonal Discharge (m^3)

Season	WS(m/s)	Q1	Q2	Q3	Q4	Q5
Dec-March	5.68a	0.06	0.69	0.57	0.45	0.30
April-July	4.40b	0.03	0.32	0.44	0.35	0.28
Aug-Nov	4.76c	0.03	0.40	0.48	0.38	0.30
Annual	4.95d	0.04	0.45	0.49	0.40	0.30

Where: WS = seasons average wind speed

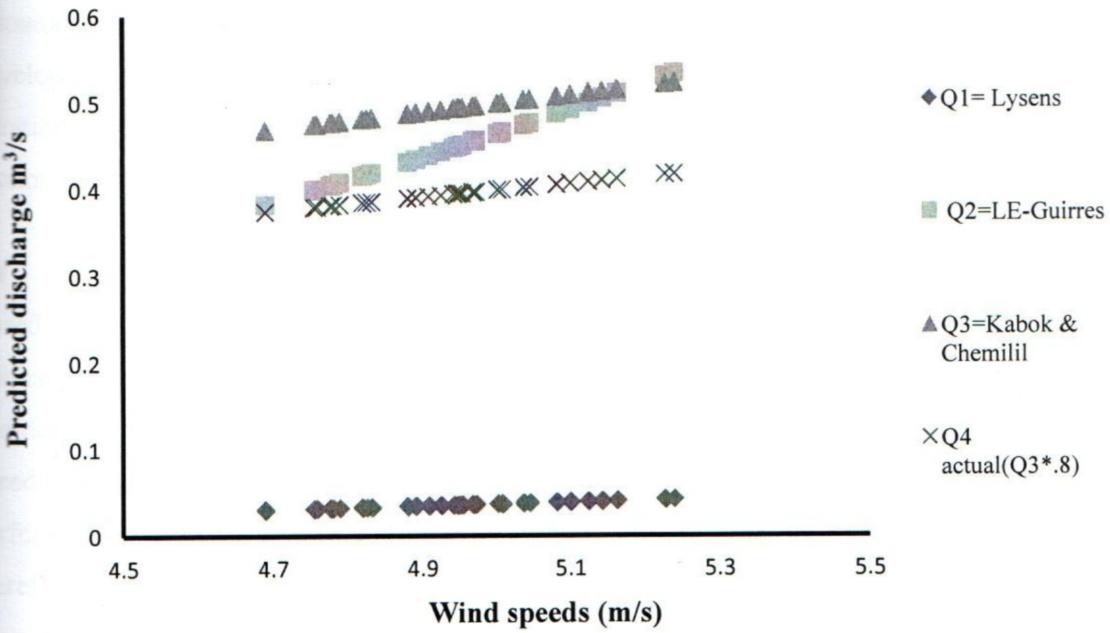


Fig: 4.5: **Predicted Discharge for annual average speeds Kisumu (2006-2011)**

This study shows that it is possible to use the hourly recorded wind speed data and the instantaneous discharge equations to estimate the days discharge based on seasons. The data in Table 4.2 is based on the daily average; a smaller time step table can be obtained from Tables A4.6 & A4.7 in the appendix of 8hrs, 10 hrs or 12hrs, which can be developed for the exact irrigation duration. Daily average wind speed data may also be assumed to exhibit the percent wind speed availability within numerical selected ranges.

The same procedure with daily recorded data is not practical for specific time measurements daily, monthly for a number of years. An approach similar as above based on daily average data was attempted. It was noted that daily average wind speed data do hide more variability's as compared to the hourly data. Hourly records or smaller time steps are hence preferred. This is because daily data are average and will need a large amount of data (3600*24*30 *12) to cover for hourly variations. Inherently therefore, it can be less accurate with few data points as this will need years of record to obtain the most approximate wind speed for each day of the month. Deciding on the duration of wind speed strengths within the 24 hours of the day will also be difficult. The hourly wind speeds allows decision on the time step of irrigation or duration and the wind speed strength available.

4.3.2 Depth and Area of Irrigation

This approach developed is to be used together with drip irrigation, especially the instantaneous wind pump discharge equations, the hydraulic and resource equations. The developed procedure and equations, where appropriate can be used to estimate the irrigation duration discharge from measured wind speeds and thus irrigation area and depth as in section 4.2.5.

4.4 Conclusion and Recommendations

Based on shorter time step and length of wind speeds measurements and the instantaneous discharge equations, the discharge for wind pump drip irrigation can be determined. In addition by use of the design chart (soil parameters, ET_O, the hydraulic equations, wind speeds and instantaneous discharge equations) wind pump drip irrigation can be evaluated for performance. The time and period of irrigation can also be determined with accuracy. It is therefore possible to use hourly as opposed to daily wind speeds measurements and shorter time steps to estimate the percentage available wind speeds for predetermined wind speed ranges. The longer the duration of wind speed measurement the more informative it is, as it integrates the spatial and temporal variations of wind speeds on the earth's surface. The hourly wind speeds or other shorter time step of measurements can be blocked into time of the day, seasons and annual basis to single out the duration of interest such as for wind pump drip irrigation.

It is also possible to predict or estimate wind pump discharges by using the instantaneous discharge equations whose field performance may differ with type of wind pump and the wind speeds. In this case, the developed percent wind speed based discharge equation($Q = f(\sum V_iR_i)$).compared well to the to the other discharge equations. It shows time and seasons variation much more clearly than the tables proposed by the manufacturers. Table 4.6 (in appendix) developed in this text

In the design, installation, operation and evaluation of the wind pump drip irrigation (WPDI) system a chart (conceptual frame work) was developed. It shows that discharge is the key link to the resource equation parameters particularly ETo, irrigation depth and area The irrigation depth and area hence is easily determined from the frame work.

ETo, irrigation depth and area relationship may need further field investigation for as many sites. This will be to ascertain the constant for the discharge for the instantaneous equations which may differ with the wind pump rotor diameters, type of the wind pump and even the percent wind speed range extent. There is need to employ GIS for wind speed measurements which is more accurate in terms of duration and locations of sites. Low solidity windmills need to be studied in this regard and especially in relation to wind speeds percent availability and discharge, both for electrical and rotor wind pumps

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able:A4.5: Seasonal and Annual Hourly Available Percent of Wind Speed Range

		December to March																								
		Hours																								
Windspeed Range		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	Avg
	1	0.55	0.54	0.54	0.50	0.51	0.50	0.30	0.25	0.16	0.06	0.03	0.02	0.01	0.03	0.07	0.10	0.17	0.24	0.28	0.34	0.45	0.46	0.54	0.59	0.30
	2	0.08	0.10	0.11	0.08	0.10	0.10	0.08	0.14	0.10	0.06	0.02	0.02	0.02	0.02	0.02	0.04	0.06	0.08	0.09	0.09	0.09	0.08	0.10	0.09	0.07
	3	0.18	0.20	0.19	0.19	0.20	0.19	0.24	0.29	0.22	0.18	0.07	0.05	0.05	0.09	0.10	0.13	0.14	0.20	0.21	0.24	0.21	0.18	0.22	0.19	0.17
	4	0.12	0.10	0.12	0.16	0.13	0.15	0.24	0.22	0.32	0.24	0.19	0.14	0.13	0.09	0.11	0.15	0.19	0.20	0.21	0.20	0.16	0.18	0.09	0.09	0.16
	5	0.05	0.04	0.04	0.05	0.06	0.05	0.10	0.08	0.13	0.23	0.25	0.19	0.18	0.20	0.16	0.15	0.16	0.13	0.11	0.07	0.06	0.06	0.04	0.03	0.11
	6	0.01	0.01	0.00	0.02	0.01	0.01	0.03	0.02	0.06	0.17	0.28	0.26	0.25	0.19	0.16	0.14	0.12	0.07	0.06	0.03	0.02	0.02	0.01	0.01	0.08
	7	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.05	0.10	0.17	0.16	0.14	0.13	0.12	0.08	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.04
	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.12	0.12	0.12	0.10	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.03
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.03	0.04	0.05	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	April to July																									
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	Avg
	1	0.66	0.69	0.68	0.62	0.59	0.56	0.32	0.27	0.19	0.07	0.03	0.01	0.02	0.03	0.05	0.11	0.20	0.32	0.37	0.47	0.59	0.60	0.65	0.67	0.37
	2	0.08	0.09	0.09	0.08	0.13	0.09	0.11	0.15	0.13	0.07	0.03	0.02	0.02	0.03	0.04	0.06	0.07	0.10	0.13	0.11	0.09	0.08	0.09	0.10	0.08
	3	0.18	0.12	0.15	0.20	0.16	0.21	0.27	0.32	0.28	0.18	0.13	0.09	0.07	0.10	0.12	0.15	0.19	0.19	0.23	0.22	0.17	0.17	0.16	0.16	0.18
	4	0.05	0.07	0.05	0.06	0.09	0.08	0.16	0.16	0.16	0.19	0.15	0.11	0.09	0.13	0.10	0.09	0.11	0.17	0.10	0.10	0.08	0.08	0.05	0.03	0.10
	5	0.03	0.02	0.02	0.03	0.02	0.04	0.09	0.07	0.13	0.18	0.17	0.16	0.14	0.12	0.11	0.11	0.12	0.08	0.09	0.04	0.05	0.04	0.02	0.02	0.08
	6	0.01	0.00	0.01	0.01	0.00	0.01	0.04	0.03	0.08	0.22	0.25	0.23	0.26	0.20	0.16	0.14	0.15	0.07	0.05	0.03	0.02	0.02	0.02	0.01	0.08
	7	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.08	0.13	0.19	0.19	0.15	0.14	0.09	0.07	0.04	0.02	0.01	0.00	0.01	0.00	0.00	0.05
	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.08	0.11	0.12	0.11	0.13	0.12	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.03
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.04	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.06	0.06	0.04	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

able:A4.6: Continued Seasonal and Annual Hourly Available Percent of Wind Speed Range.

		August to November																								
		Hours																								
Wind speed Range		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	Avg
	1	0.70	0.69	0.66	0.60	0.59	0.55	0.31	0.28	0.17	0.07	0.02	0.01	0.01	0.03	0.05	0.08	0.18	0.29	0.41	0.50	0.58	0.59	0.66	0.71	0.36
	2	0.05	0.07	0.09	0.06	0.11	0.08	0.09	0.14	0.13	0.05	0.02	0.00	0.01	0.02	0.02	0.07	0.06	0.06	0.07	0.07	0.08	0.08	0.09	0.08	0.07
	3	0.16	0.14	0.17	0.21	0.20	0.19	0.28	0.30	0.28	0.20	0.10	0.06	0.04	0.08	0.11	0.13	0.17	0.23	0.21	0.22	0.19	0.18	0.15	0.14	0.17
	4	0.07	0.07	0.05	0.09	0.06	0.10	0.14	0.17	0.18	0.19	0.15	0.10	0.09	0.11	0.09	0.11	0.13	0.11	0.11	0.11	0.07	0.08	0.05	0.05	0.10
	5	0.01	0.03	0.02	0.03	0.03	0.04	0.11	0.07	0.12	0.18	0.18	0.13	0.13	0.11	0.13	0.08	0.13	0.12	0.08	0.05	0.04	0.03	0.03	0.01	0.08
	6	0.01	0.01	0.01	0.01	0.01	0.02	0.06	0.04	0.09	0.19	0.27	0.29	0.25	0.18	0.16	0.14	0.15	0.12	0.07	0.03	0.02	0.02	0.01	0.01	0.09
	7	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.02	0.10	0.16	0.23	0.21	0.17	0.12	0.15	0.07	0.04	0.03	0.01	0.01	0.00	0.00	0.00	0.06
	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.10	0.14	0.10	0.11	0.10	0.06	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.03
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.04	0.06	0.06	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.05	0.05	0.07	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total Annual																									
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	Avg
	1	0.64	0.64	0.63	0.57	0.56	0.54	0.31	0.27	0.17	0.07	0.03	0.01	0.01	0.03	0.06	0.10	0.18	0.28	0.35	0.44	0.54	0.55	0.62	0.65	0.34
	2	0.07	0.09	0.10	0.07	0.11	0.09	0.10	0.14	0.12	0.06	0.02	0.02	0.01	0.02	0.03	0.06	0.06	0.08	0.10	0.09	0.09	0.08	0.09	0.09	0.07
	3	0.17	0.15	0.17	0.20	0.19	0.20	0.26	0.30	0.26	0.19	0.10	0.06	0.05	0.09	0.11	0.14	0.17	0.20	0.22	0.23	0.19	0.18	0.18	0.16	0.17
	4	0.08	0.08	0.07	0.10	0.09	0.11	0.18	0.18	0.22	0.21	0.16	0.11	0.11	0.11	0.10	0.12	0.14	0.16	0.14	0.14	0.10	0.11	0.06	0.06	0.12
	5	0.03	0.03	0.03	0.04	0.04	0.04	0.10	0.07	0.13	0.20	0.20	0.16	0.15	0.14	0.13	0.12	0.13	0.11	0.09	0.05	0.05	0.04	0.03	0.02	0.09
	6	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.03	0.08	0.19	0.27	0.26	0.25	0.19	0.16	0.14	0.14	0.09	0.06	0.03	0.02	0.02	0.01	0.01	0.09
	7	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.08	0.13	0.20	0.19	0.15	0.13	0.12	0.07	0.04	0.02	0.01	0.01	0.01	0.00	0.00	0.05
	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.10	0.13	0.11	0.12	0.11	0.06	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.03
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03	0.05	0.05	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03	0.05	0.06	0.04	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CHAPTER FIVE

FIELD INSTALLATION AND PERFORMANCE OF A WIND PUMP DRIP-IRRIGATION SYSTEM AT LAKE VICTORIA, KENYA

Abstract

The Ngura and Rusinga Lake shore sites were used for characterizing installation of wind pump drip irrigation (WPDI) system. The system comprises of the wind pump, water reticulation network and the drip irrigation unit. Lack of adequate data prompted the use of situational estimates. The aim was to establish precedent aspects and determine parameters that affect wind pump drip irrigation system installation and its irrigation efficiencies. The parameters considered were wind characteristics, discharge and the Evapotranspiration (ET_o) while the aspects were location, water quality, quantity and availability. Both historical and onsite data were used. It was established that water quality variables need monitoring throughout the life time of the system with initial values as datum. There was a 0.5 m. Lake level drop which translates to 30-35 m horizontal distance recession along the perimeter of the Lake. Reference evapotranspiration (ET_o) according to Penman were comparable to the LocClime software estimator for its higher but not the lower value estimates. Synchronization of water requirement for the plant and the irrigated area (system discharge), wind pump output characteristics and the emitter discharge were considered. Drip-irrigation efficiencies namely design emission uniformity (E_U) and absolute emission uniformity (E_{Ua}) were acceptable and varied between 93% in the morning to 94% in the afternoon for the thirty-nine test-runs made. Subsequently the technology was considered realistic, replicable and applicable but would be more useful in areas faced with weather vagaries and with favourable wind regimes. Application of GIS and use of satellite would eliminate the challenges of inadequate data and improve on the accuracy of estimates.

5.1 Introduction

The wind pump drip irrigation (WPDI) system has three main parts; the wind pump, pipe network and drip irrigation set up. A water storage tank may be included. The requirements for implementation at any site includes availability of water and its quality, the land topography and locality, type of soils which influences the percentage wetted soil (W_P and soil constant K_r for non-beneficial evaporation) and crops. The factors for installation are wind characteristics (speed and duration), discharge, and the crop irrigation characteristics (the gross water requirement IRg, the reference Evapotranspiration ET_o).

The hydraulics of network pipeline and drip irrigation is also a key factor in design (Lakhdar and Ahmed, 2005). Chumo *et al.*, (2011) noted that data collection and availability are highly influenced by the prevailing economic conditions in a country, especially in the developing world.

The wind speeds directly influence the energy content, which should be evaluated for its availability and variability with time (Qamar, 2011). This requires appropriate data, choice and use of the predictive equations as appropriate, density and sustenance of measuring facilities. Hence to install such a system adequate data and understanding of the drip-irrigation, wind and pump characteristics need a thorough situational review.

The need for proper planning and water management is vital in irrigation decisions; it covers the source of water to the point of utilization. The crop water requirement refers to the actual amount of water needed for evapotranspiration (ET_{crop}) and plant growth; this is influenced by the crop development and the prevailing climatic conditions. Irrigation requirement also depends on the irrigation system efficiency (Ea), management practices and the soil characteristics in the field. Farmers at lakeshore (Ng'ura and Rusinga) supplement their horticultural crops through irrigation efforts. They have been using buckets and hand dug canals from the lake to the hinterland which is faced by a number of challenges including time wastages and is labour intensive thus limiting the area of irrigation. The Ngu'ra wind pump was a new development that illustrates the aspects of field installation and how parameters are determined while the wind pump at Rusinga demonstrated the procedure for the drip irrigation field system performance.

The approach integrates the use of wind pump and crop production as influenced by spatial and temporal wind variations at the Lake Victoria shore, Kenya. The existence of adequate prevailing winds at LS can be tapped to drive WPDI systems which offer an alternative form of irrigation that delivers the water at pre-determined points with less water losses in the field. The WPDI system study presents: - i) precedent requirements for Installation (Ngu'ra) (ii) test-run of a direct coupled wind pump driven drip-irrigation system (Rusinga) along the shores of Lake Victoria with respect to changing wind speeds and discharges. The specific objectives were to:

1. Determine the precedent aspects and parameters for installation of a wind pump drip irrigation system.
2. Establish the efficiency of the wind pump drip-irrigation system.

5.2 Materials and Methods

The precedent aspects for installation of a wind pump drip irrigation system along the Lake Victoria Shore are enumerated as; location, intake works, water delivery to the crop, lake level fluctuations; and water quality and availability. The parameters are wind speeds, reference evapotranspiration system discharge and irrigation efficiency.

5.2.1 WPDI design and installation.

a). Development

The aspects and parameter relationship are summarized in figure B 5.1 as the irrigation location (IL), Manufacturer (MF), wind pump (WP), wind regime (WR), crop water requirement (CWR), Emitter discharge (ED), Wind pump rated discharge (SD_1), Discharge based on crop water requirement (SD_2) and the Irrigation Designer (IRD). A balance should be when WP as the INPUT (abstraction) corresponds to CWR on the SINK side, and that SD_1 should be just greater or equal to SD_2 dependent on design efficiency.

WPDI system is hence synonymous to emitter as the sprinkler head, motorized pump becomes the wind pump (WP) and wind regime (WR) serves to illustrate the variable horsepower of the pump which depends on spatial variations (locations, IL). The installation process of WPDI illustrates the approach, procedure and use of the key parameters, though there are challenges. The discharge availability as a key element of the system output is defined by the relationship $SD_1 \geq SD_2$. The aspect of the system water quality is taken care of at the preliminary assessment and analysis. It is important in the management and operation of the system.

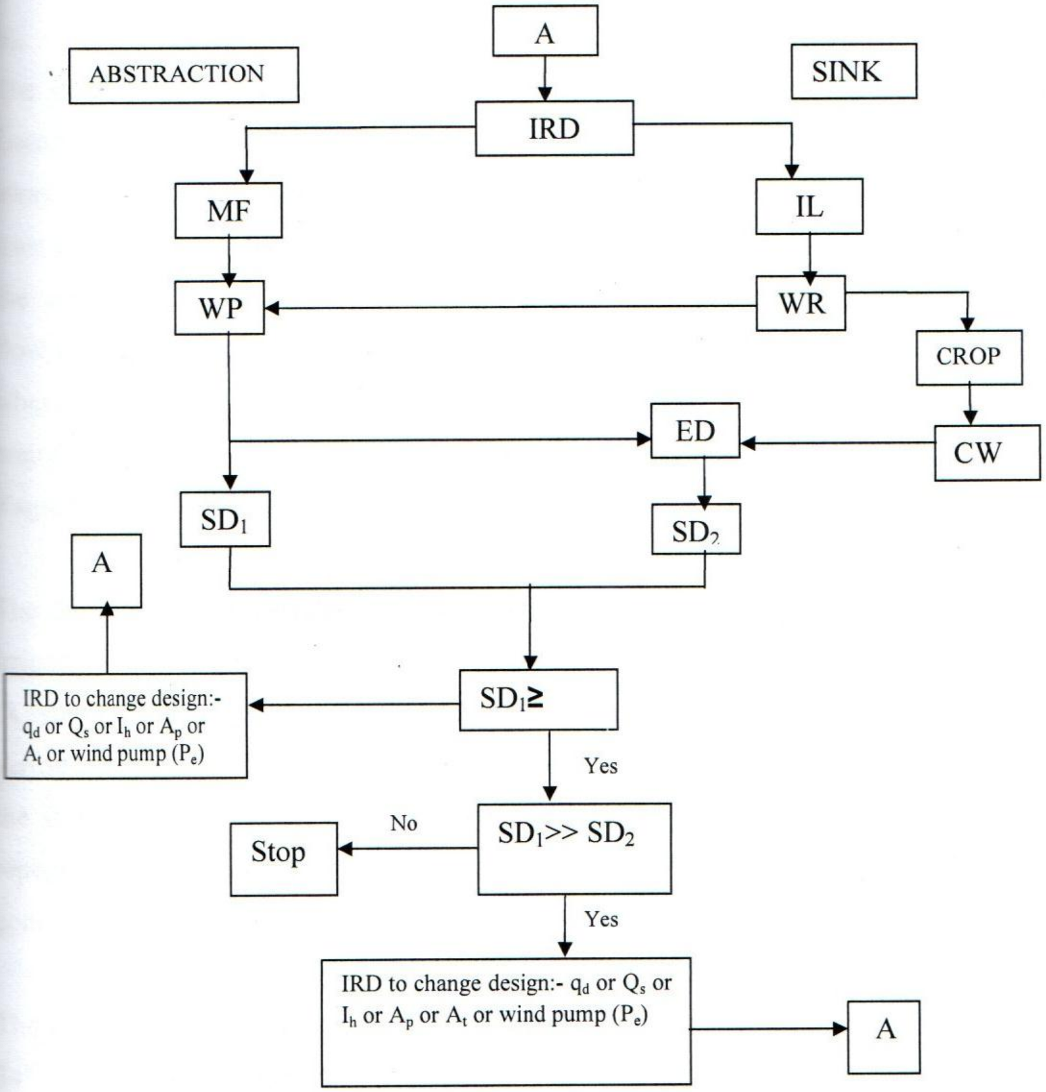


Fig: 5.1: Wind Pump-Micro-irrigation Design Illustration Chart

Where IL = irrigation location, MF = Manufacturer, WP = wind pump, WR = wind regime, CWR = crop water requirement, ED = Emitter discharge, SD_1 = Wind pump rated discharge, SD_2 = Discharge based on crop water requirement, IRD = Irrigation Designer.

(i) WP on the INPUT (Abstraction) side corresponds to CWR on the SINK side.

(ii) SD_1 should be just greater or equal to SD_2 dependent on design efficiency.

(iii) The chart Fig. 5.1can be applied elsewhere for the design of a sprinkler irrigation but developed for a wind pump (horizontal axis) micro-irrigation

b). Location

The study was conducted at Ngu'ra and Rusinga sites. Ngu'ra is situated in East Kanyada Location, Asego Division in Homa Bay County. It is surrounded to the east by a hill (3.5 km away) and a lake to the West (1.5km away). It experiences both land and sea breezes, to the west the wind fetch distance originate from the lake. While to the North and South directions the wind fetch distance is along the high ground and the lake water boundary. Other wind flow interruptions are due to vegetation and tree cover in all the directions except to the west where it borders the lake, 68,000 km^2 (Kayombo and Jorgensen, 2009), hence water forms the major frictional layer to wind flow. The wind pump was installed 2km downstream of Ragwena Bridge off Homa Bay – Kendu Bay road (Figures B5.6 and B5.7 in the Appendix).

The decision for the selected site was based on the community's request to have water for irrigation and domestic use. The Lake Victoria shoreline is 550 km long on the Kenyan side (Kayombo and Jorgensen, 2009) with many suitable sites for irrigation. In terms of the surrounding topography and orientation, the sites were considered suitable from observations, the topographical surveys and that farmers were growing various horticultural crops. A topographical survey was carried out to show the water intake point and topographical contours, as in Figures B5.6 in the appendix.

The Rusinga wind pump at Tom Mboya High School, lies at latitude 00° 30'S and longitude 34° 15'E in Kenya. The wind pump was installed on a hand dug well located at a site 10m off the Lake Victoria shore. Westward of the site was a long stretch of lake water towards Tanzania and Uganda. Eastward, Northward and Southward there was an interruption of wind flow by the Rusinga Island ridges that surrounded the pump site in form of figure C curvature/ shape. Approximately 290m away from the wind pump there was the designed pilot irrigation unit that branched off into a drip-irrigation head control unit (Figure 5.7 in the appendix),which is supplied by a 50 mm galvanized iron main pipe. This is where the wind pump drip-irrigation system was established and its performance (efficiencies) was determined. The choice of site and aspects are important to wind pump drip irrigation system installation.

c) Wind Pump Installation

The main water line at Rusinga site was installed for the purpose of water supply to serve Tom Mboya High school and the Hospital. The Ngu'ra water system comprised of the intake works, the infield water delivery system and a tank situated at 1.2 km away from the wind pump.

Both systems were provided with a storage tank. A topo-survey was initially undertaken for each of the area to be irrigated. Additional activity at Ngu'ra was to determine the invert level for laying the main pipeline from inlet to the wind pump, inclusive of the intended irrigation abstraction points. The wind pump sump position was then sited and a profile survey taken linking its location to the lake water level. The soils were also checked by observation and as in Jaetzold and Schmidt (1982) so as to determine the suitable footing requirement for the wind mill. This was further verified by the Rural Domestic Water Resources Assessment Report (DHV 1987), that has detailed hydro geological study of South Nyanza District, which covered the Ng'ura area.

The intake works for Ngura comprised of installation of a double pipe line (150mm dia) that extended beyond the shoreline into the lake water from a hand dug well as the reservoir to the wind pump, a designed sedimentation tank and an inspection chamber as the last unit to the lake water. The extension to lake was to avoid dirt due to wave action at the shore line. The two chamber sedimentation tank (9 m by 2.5 m by 3 m) was dug below the ground level to correspond to the water entry point to the wind pump sump.

The total depth of the well was approximately 4m below the ground level while the lake water level measured 2m below the ground at wind pump sump position. The hand dug well was reinforced by 1m diameter concrete pipes to avoid collapse of the clay soil walls. The invert level of the pipe intake was set below the lake water level. On the well, a reinforced slab was laid and a circular entry point left for the Wind Pump rod, the wind mill was then installed on the slab with three reinforced footings, each rectangular in shape with a size (0.6 m by 0.6 m) and approximately 1.2 m in depth. The wind mill supplied by Kijito Ltd. Kenya was in three tripod pieces that fitted onto each other. The first tripod piece was anchored on to the footings held by a flap plate laid onto bolts. All the other tripod pieces were assembled vhile on ground together with the wind mill. A winch lorry was then used to lift the whole ripod for fixing on to the footing. The rest of the parts were thereafter fitted including the ump.

l) Water Delivery

A 50 mm diameter polyethylene pipe of grade D Kenya Bureau Stands (KBS) was laid nderground at an average depth of 450 mm (at Ngu'ra) to deliver water to a water holding ank 1.2 km away. The pipe laying started after an air chamber and a non-water return valve rom the wind pump. Between the non-return valve and the water tank, the main delivery ipe was laid at an average slope of 0.6% as shown on irrigation area map. The Ragwena tream interrupted the pipe laying (Figures 5.6 in the appendix) and was crossed along the ed formation. The pipe thereafter was laid along a smooth rising slope until delivery to the op of the tank. Along the main pipeline, there were off takes of 50 mm (diameter) that were lesigned and installed to deliver the water to the sub mains 25mm which subsequently lelivered water to the irrigation fields. The first off take was at 20 m from the wind pump. The next were installed 100m equidistant from each other up to the Homabay- Kendubay oad. Each of the off takes comprised a 50 mm Tee, a 1m pipe length stand pipe, a 50 mm end, a 50 mm gate valve, a socket and short length straight 50mm pipe. The gate valve is sed to regulate water flow in the pipe network. The irrigation field was laid with flexible lrip line hoses with clips at the start to be fixed and removed as was needed. The same set up vas adopted for the head works for the single irrigation unit (1000 m^2) as was set at Rusinga Figure B5.7 in the appendix).

The irrigator can either use a hose entirely or connect it to a drip system. Figure B5.7 in the ppendix illustrates the water application point from the wind pump to the plant. A reservoir ank was provided with a lockable outlet connected to the same delivery line. An off take line herefore had two supply sources, the backwater flow from the tank or direct wind pump supply. The off take supply from the tank should always be on the side not receiving the lirect water delivered by wind pump. The backwater supply was put in place to benefit from he night storage. Suitable gate valves were put in place to regulate water flow in the system. A hose line attached to the off take can therefore be used to deliver water to the micro basins/furrows or connected to a drip unit as was suitable to the farmer. The irrigation pressure head was provided by both the tank and the wind pump. The main irrigation pressure control was achieved by essure compensating emitters and the stable irrigation duration determined by wind nsistencies.

Water Quantity, Quality and Availability.

e possible sources of water at the Ngu'ra wind pump site Figure 5.6 were ground aquifer, ke Victoria and the Ragwena stream. The stream is seasonal while the lake water fluctuates level with seasons. The Ragwena stream is 15m to the wind pump installation site. Ground ter possibility at Rusinga and Ragwena were assessed and found not adequate based on the HV (1987) hydro geological map and the local information and observations made at the e.

e water at Ragwena River and around the project area was sampled for quality analysis. e Ragwena wind pump installation site was located barely 100 m off the lake water and out 3 km direct distance north off the Homa bay sewage treatment (lagoon).The sampling ints were located along the shore line of the Lake to determine the influence of the Lagoon the wind pump site. The five sampling sites were: Homabay Township next to the lagoon, shops house 2.5 km from the site, next to wind pump location, at Ragwena river mouth and the Ragwena bridge. The Bishops house is between the wind pump site and the Homabay goon. The water qualities were examined at these positions to enable advice on both gation and human consumption.

Lake Level Fluctuations

e lake water level was monitored for the wind pump placement at the shore. In setting the el of the inlet from the lake to the wind pump sump, the fluctuation of the lake water level s predicted from the records of Kisumu pier for the years 1964 to 2005. Four graphs of ge height against years were generated, one for the period 1964 to 2005 and the other ee comprising data of two decades each for the duration of the records.(Fig 5.1).

.2 The Parameters

Reference Evapotranspiration

termination of evapotranspiration (ET_o) within the LS is a challenge because of inadequate a that hampers the use of the resource equations (Chumo *et al.*, 2011). The data at the six (Kisumu and Kadenge, Kibos and Ahero and, Muhuru bay, Kisumu and Rusinga) sites re examined for conformity to the existing ETo equation. Obtaining all weather parameters (temperature, rainfall, sunshine intensity, wind speed and relative humidity) required was difficult due to scanty records. Therefore ETo estimate for the LS stations was based on Penman equation, using an ETo calculator (Dirk, 2009). The results from Penman method and Hagreaves were compared with the new LocClim 1.10 (which had reasonable amount of data.).

The monthly average reference evapotranspiration and wind speeds from the weather stations within the LS were first compared with that from the LocClime software. This method was adopted after trial with satellite data proved inconsistent. The LocClime software generates reference evapotranspiration data which was designated as low and high, based on the 2m height normally for agricultural weather monitoring. The compared performance was used to estimate ETo at site(s) that did not have records within the LS, for example the Ng’ura site.

The accuracy of these formulae mentioned above remains untested within the LS region. Chumo *et al.,* (2011) concludes that Blaney Criddle (1950) method may be the best estimate of potential evapotranspiration within the Lake shore. However, the variability of the data used and poor equipment used posed an inconclusive decision on its usability. The nearest station tested by use of lysimeters is at Kericho Tea Research Foundation (Lat: 0° 22’S, Long: 35° 21’E, Alt; 2178m a.s.l.), to determine the tea crop water requirement. The LS area of study was taken to have little weather parameter variation. The stations were also chosen to show the performance of the methods with respect to location. Procedures for applying the ET_0 procedures are shown by Doorenboss *et al.,* (1977); Chumo *et al.*, (2011).

b) Wind Speeds

The wind speed and ET_0 for Rusinga was calculated from historical data obtained from a station within a distance of one kilometer of the wind pump site as in Table 5.1. It was however not in use and the 2 m height wind speed data indicated speeds range from 2 m/s to 3m/s. The initial preliminary wind measurements at the wind pump site showed the range to be within the 3m/s to 4m/s as later confirmed from the observed data taken from October to December season.

ble:5.1: Rusinga and Ng'ura Mean Monthly Wind Speeds (m/s)

Month	N	Missing	Mean	SD
Jan	341	0	2.94	0.57
Feb	311	30	3.08	0.65
Mar	341	0	2.99	0.60
Apr	330	11	2.60	0.52
May	341	0	2.28	0.43
Jun	330	11	2.32	0.38
Jul	341	0	2.45	0.45
Aug	340	1	2.56	0.43
Sep	330	11	2.62	0.41
Oct	341	0	2.63	0.52
Nov	330	11	2.61	0.66
Dec	340	1	2.78	0.47
Annual Avg	335.67	6.3	2.65	0.508

is number of observation, SD is the standard deviation.

Ng'ura, there was no nearby weather station to help in the estimation of the crop weather ameter especially evapotranspiration (ET_o). The reference evapotranspiration (ET_o) values e arrived at by use of data from Kisumu, Rusinga and LocClime software. This was ause they exhibit similar features to Ngu'ra. The wind speeds data were used in allation of wind pump and for the design of the drip irrigation system.

.3 Wind Pump drip Irrigation system efficiency

Discharge

key parameters for the WPDI system discharge were wind speeds and the reference potranspiration; Ng'ura site illustrated a case where both the data and parameters were not ilable while Rusinga, had inadequate data pts. They were respectively used in illustrating gle off take WPDI (Figures B5.6 and B5.7 in the appendix) design and how the system charge performance was determined. The process is repeatable for all the outlets (off es) and the variable discharge along the pipe line.

he system discharge for the wind pump was determined according to Vermeiren and Jobling 980) and Seleshi *et al.,* (2009) as illustrated in the result's Table 5.11 in section 5.5.5 and it ded in estimation of system discharge for Ngura. The parameters of crop water requirement s a factor in the design are summarized in the following equations (5.1 to 5.4) and Table .11. The evapotranspiration values were calculated from E_{Pan} data and used to derive IR_g nd IR_n values together with the other parameters shown in the results Table 5.11 in section .5.5.

$$IR_n = ET_{crop}.K_r - R + L_r \tag{5.1}$$

$$IR_g = (F_c - W_p)d_m.R_z \times {}^{P}/_{100} \cdot \gamma_b \tag{5.2}$$

Or

$$IR_g = ET_{crop}.K_r.E_a + L_r - R \tag{5.3}$$

$$E_a = K_s E_u \tag{5.4}$$

here: IR_n = net irrigation water requirement, L_r = leaching requirement, R = water received y the plant from other sources other than irrigation, IR_g = irrigation requirement. F_c = olume moisture at field capacity (%), d_m = maximum allowable depletion (%), R_z = soil epth or root zone to be considered in meters, P = volume of the soil wetted as a percentage f the total volume, and γ_b = bulk density of the soil (others as defined in Table 5.11). K_s = ater storage efficiency, E_u = design emission uniformity. Wp= Wilting point.

he wind pump performance Table 5.2 was used to determine the discharge at the specific off ake. The Table shows the pump head (H_s) in meters, diameter of the rotor, wind speed nterval (m/s) and the corresponding discharge. Table 5.2 illustrates the arrangement given by he manufacturer, which was modified in the top row by replacing discharge with wind speed nd by adding columns below. The table shows percentage head loss (J) and head loss (H) ithin the pipeline. The J, H and Q values are variables of size and length of pipe; in this case y were specific to the main line of 50 mm diameter with length of 290m. The H_s values en include head (m) due to mainline.

Table:5.2: Calculated J & H Values - Based on Kijito Wind Pump Performance

			Wind speeds (m/s)						
Head (H_s) (m)		**2 – 3**			**3 – 4**			**4 – 5**	
0	J	Q/Qo	H	J	Q	H	J	Q	H
0	0.64	0.79	1.86	4.3	2.21	12.6	18	4.71	51
0	0.2	0.42	0.58	1.25	1.13	3.6	5	2.38	14.4
0	0.12	0.21	0.16	0.32	0.54	0.92	1.3	1.17	3.9
20	-	-	-	0.17	0.38	0.48	0.6	0.79	1.86
60	-	-	-	0.1	0.29	0.29	0.4	0.58	1.05
00	-	-	-	0.06	0.21	0.17	0.2	0.46	0.69
40	-	-	-	-	-	-	0.2	0.38	0.48

tor diameter = 6.1m

ere, J= Headloss in percent of pipe, Q = system discharge, Hs = determined total head for drip-irrigation unit, topographic head (H), manifold and main line/others of 22.15-; (m)

for the Rusinga wind pump case, the discharge was obtained from Table 5.2 based on ure B5.7 in the Appendix against the calculated head and compared to the standard culated water requirement to specify the system discharge (Q_s). These corresponded only er varying some of the limiting factors such as suitable emitter discharge, system charge, irrigation interval, duration and area as shown in Table 5.3. Instinctively, the wind np output should be greater than or equal to the calculated crop water requirement so as to isfy the crop water requirement. All together, the size or length of the pipe can be varied, v values obtained and the calculations repeated.

Table:5.3: Micro-irrigation System Parameters

Parameter	I	II	III	IV	V
q_d (L/hr)	3.5	18.4	3.5	3.5	3.5
Q_s (m^3/hr)	0.86	4.6	1.7	0.79	0.86
I_i (days)	3	12	5	3	3
I_h (hours)	16	12	12	7	16
P_e (m)	10	10	10	10	10
A_P (m^2)	2 x 2	2 X 2	0.9 X 2	0.9 X 2	2 x 2
A_t (ha)	0.1	0.1	0.09	0.04	0.1

where: (q_d)= suitable emitter discharge, Qs =system discharge, I_i=irrigation interval (I_h)=irrigation hours and (A_t)=irrigation area P_e is the pump elevation, I to V= roman numbers for choice of a suitable emitter.

The Rusinga main line was previously installed for purposes of water supply to a school and the hospital. The wind pump drip-irrigation system was installed on the mainline through a combination of design and a check on hydraulic characteristics. This was by use of Hazen William's equation together with Christiansen's (1942) modifying factor (F) for the system discharge in the design of the hydraulic system, the manifold and the laterals as shown in Sadeghi *et al,* (2011). The 20% rule (Benami and Ofen, 1983) was used to achieve the maximum allowable range of uniformity coefficient (C_u) for the drip irrigation. The irrigation interval (I_i) and system discharge (Q_s) were calculated based on CWR equations 5.1 and 5.2 and by specifying the other parameters as listed in Table 5.3.

A choice was made for (q_d), (Q_s), (I_i), (I_h) and (A_t) taking into account to Table 5.3 but pegged on values of q_d and Q_s. Emitter discharge choice was based on crop spacing to ensure that the discharge point was at the foot of the crop and type available. Change of any of the variables of equations (5.5 and 5.6) also adjusted the Q_s and q_d. In Table 5.3, only q_d and P_e were reasonably held constant among the five option choices, signifying specific emitter and wind pump. The guideline was to design an option with parameters that complied with 3.5 l/hr emitter size, wind pump/wind regime capacity of 3-4 m/s or water available, crop water requirement and system discharge (Q_s) of 1.7 m^3/hr restricted by the wind pump.

$$Q_s = q_d \,.\, I_i \,.\, {}^{A_t}\!/_{A_p} \,.\, 10 \tag{5.5}$$

From

$$q_d = IR_g \,. A_p/I_h \ \ and \ \ Q_s = I_i . A_t . IR_g . 10/I_h \tag{5.6}$$

five system optional operational conditions were developed as in Table 5.3. Option V selected at preliminary design stage because, one lateral was damaged and secondly, the st emitter spacing obtained in the market was 0.9m and this changed at installation stage. of option III indicted that the wind pump was able to provide 1.7m³/hr, contrary to what expected from the Rusinga historical wind data and performance of the Kijito wind p. In order to fully determine the irrigation period, the issue of the threshold wind speed ability needed to be answered and it formed the basis of wind speed availability in terms terval and period of measurement.

Field Evaluation of the Drip-irrigation

uation was carried out at Rusinga and expressed in the following equations.

$$E_a = K_s E_u \ \text{or} \ 100{,}000/K_s\,E_u \tag{5.7}$$

re: E_a = irrigation efficiency, K_s = water storage efficiency, E_u = design emission ormity. Other aspects of drip-irrigation evaluation that were considered are monitoring of oil inactive exchange with the water/the nutrients, the percentage-wetted soil (p). K_s and %) were both estimated.

rizontal axis wind pump was directly - coupled to a drip-irrigation system at Rusinga d and its field performance established by 39 test runs for a period of 20 days and 10 tes each. The choice of time of test-runs was such that it captured the difference in the speed pattern of the area, three times daily for the period of the tests (10.30, 12.30 and 0hrs).

The Kijito wind pump was the main power source for the 900m^2 drip-irrigation unit with pressure compensating emitters. The unit was designed for mature passion fruits and had emitter spacing of 0.9m x 2m limited by market availability. The Potential evapotranspiration was determined by Pan Evaporation method.

The other irrigation parameters related to climate (effective rainfall, ET crop and soils (Leaching Lr) were either calculated or estimated.

The study used the procedures proposed by Bralts (1980) and Vermeiren *et al.,* (1980) to determine the uniformity of distribution (E_u and E_{ua}) as given in equations 5.8 and 5.9. During the test runs, ten minutes was selected for turn on and off of inflow to the irrigation unit. Pressure reading was only taken at the head control unit because of lack of pressure gauges and proper attachment equipment. A sample field test-run (Table 5.4) together with field layout (Fig. B5.7) shows the test-run details.

$$E_u = \frac{Minimum\ rate\ of\ discharge\ per\ plant}{Average\ rate\ of\ discharge\ per\ plant} \ldots\ldots\ldots\ldots\ldots\ldots \text{(5.8)}$$

$$E_{UA} = \frac{100}{2}\left[\frac{q_{min}}{q\ _{avg}} + \frac{q_{avg}}{q_x}\right] \ldots\ldots\ldots\ldots\ldots\ldots \text{(5.9)}$$

Where E_u = field emission uniformity as a percentage, q_{min} = minimum discharge rate computed from average of the smallest four readings per test run, q_{avg} = average of all the field data emitter discharge rates, E_u= design emission uniformity (Keller and Karmeli, 1975; Pankaj, 2013), E_{ua} = absolute uniformity as a percentage and q_x = average of the highest one-eighth emitter flow rates.

Table:5.4: Sample Field Micro-Irrigation Test Run (3.20 - 3.30 pm)

		LOCATION OF LATERAL ON SUB MAIN			
Distribution Location on the Lateral		Inlet End Discharge (l/hr)	$^{1}/_{3}$ Down Discharge (l/hr)	$^{2}/_{3}$ Down Discharge (l/hr)	Far End Discharge (l/hr)
Inlet End	A	3.6	3.7	3.5	3.4
	B	3.5	3.6	3.4	3.5
	Time (Min)	10	10	10	10
	Aver.	3.6	3.7	3.5	3.5
1/3 Down	A	3.3	3.3	3.5	3.4
	B	3.4	3.4	3.4	3.3
	Time (Min)	10	10	10	
	Aver.	3.4	3.4	3.4	3.4
2/3 Down	A	3.5	3.3	3.3	3.4
	B	3.5	3.3	3.4	3
	Time (Min)	10	10	10	
	Aver.	3.5	3.3	3.4	3.2
Far End	A	2.9	3	3.1	3.1
	B	3.1	3.3	3.4	3.4
	Time (min)	10	10	10	10
	Aver.	3.0	3.2	3.3	3.3

5.3 Results and Discussion

The design and performance evaluation of a wind pump drip-irrigation (WPDI) system at the Lake Shore required that the aspects and parameters were either accurately determined or estimated dependent on the conditions for implementation. Though the hydraulic calculations are routine process, challenges are occasioned by the spatial and temporal variations of wind speeds. Chumo *et al.*, (2011) recognizes that each region requires an established method for accurately determining ET_O (PenMan Equation, Radiation, Pan Evaporation and Blaney-Criddle Methods). Knowledge of the crop development stages, ground cover, management practices and climatic conditions are important in determining the crop coefficient (K_C). Other factors include the percentage-wetted portion of the total soil volume (W_P) and the non-beneficial evaporation (K_r), which occurs in the conventional irrigation methods. Research is necessary to circumvent the challenges of obtaining information for every locality.

Economic conditions often do not allow for this and especially in the developing world. This is coupled with the wind regime which should be synchronized to only a particular design of a wind pump.

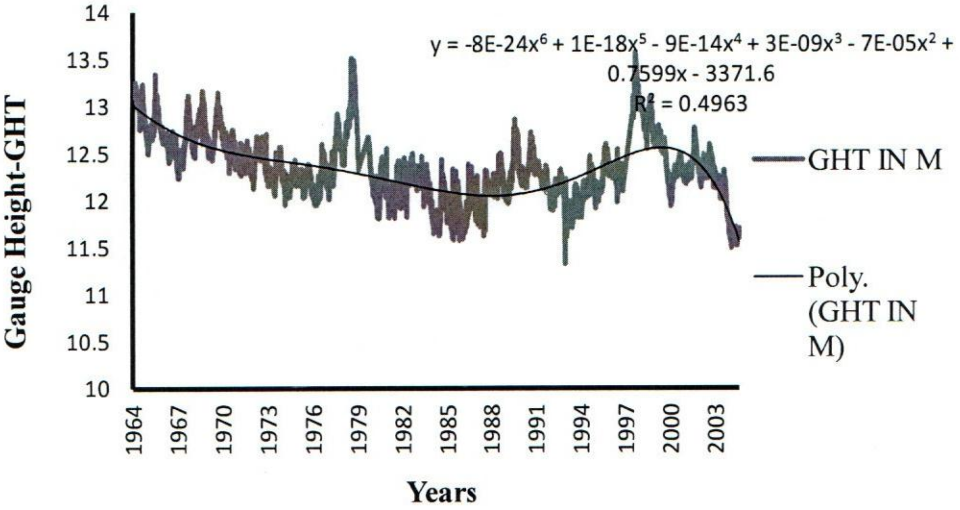
Equivalently, there are various approaches to the characterization of wind regime, problems with data availability, choice and use of predicting equations, density and sustenance of measurement facilities especially in the developing countries. Hence before embarking on the design and performance procedures, adequate understanding of the conditions of the drip-irrigation, wind, wind pump and their performance need a thorough situational review. Figure 5.1 may also serve to explain this. It also symbolizes a sprinkler design where emitter is the sprinkler head, motorized pump becomes the wind pump (WP) and wind regime (WR) serves to illustrate the horsepower of the pump, which may be varied for the same environment. The challenges may be quite specific but the design approach and performance procedures above illustrate key parameters required.

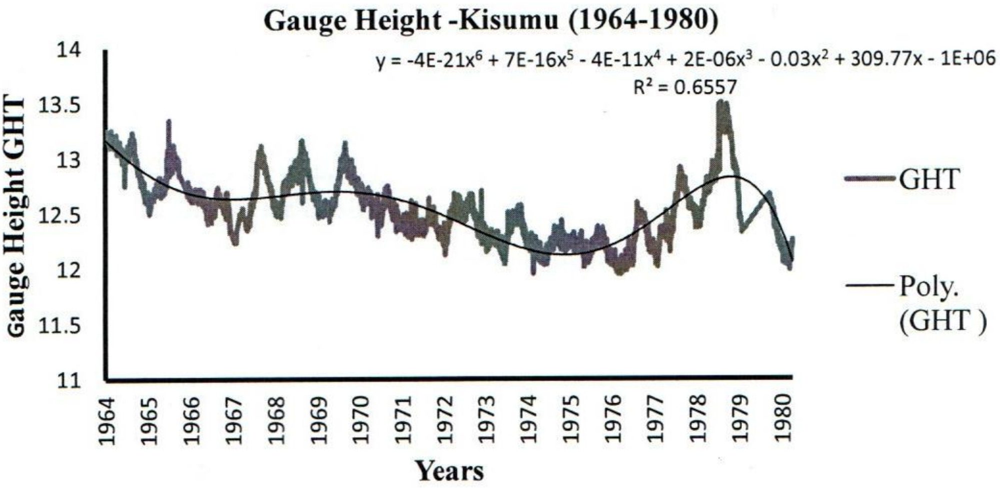
Another factor was the water availability and quality, the availability defined by crop water requirements and wind pump operating output at the available wind regime (Q_s). Water quality for the system was taken care of by the preliminary assessment and appropriate filters introduced (Table 5.5). Solution to issues on aspects and parameters are hence illustrated below for the determination of field performance of wind pump drip irrigation.

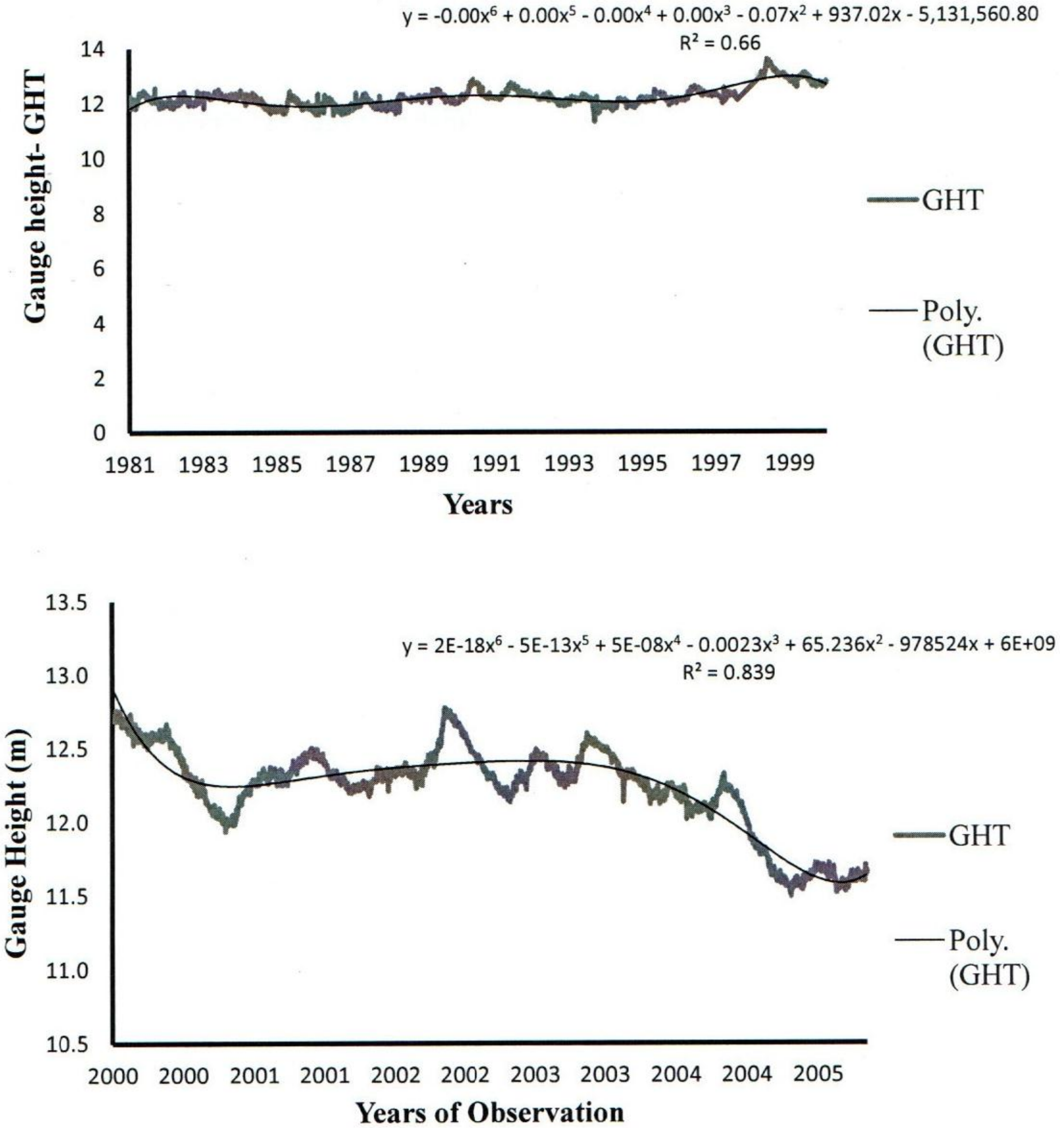
5.3.1 Lake Fluctuations and Pump Well Bottom Level

The Kisumu lake level gauge height data (1964 – 2005) used as reference varied from 13.06 m to 11.5 m. The lake level variation as is observed in segments of two decades were as follows; (1964 – 1980 is 13.06 -12 m), (1981 – 1997 is 12.5 – 11.5 m) briefly increasing from 12.5 to 13 m between 1998 to 1999; 2000 – 2004 (12.7 - 12.00 m) and from 2005 the drop was from 12.5 m to 11.5 m. As is in Figure 5.1 the level fluctuated showing a declining trend for each of two decades oscillating on an up and down boundary range of one meter. By the year 2005 the oscillation dropped from 13.06 – 12 m in 1964 to 11.5 m to 12.5 m indicating a reduced lake level depth of 0.5 m. The fluctuations lower limit range is therefore tending towards gauge height of 11.0 m or lower. This is indicating that the depth of the Lake Victoria in Kenya is declining.

he 0.5 m drop from the site topographical survey showed a 30 - 35 m horizontal distance ecession of the lake level. This could be less or more along any of the perimeter of the Lake ictoria. The low lake level should be monitored once in 10 years which is an important actor for positioning and laying of the water intake, intake line or the profile and this is onsidered together with the fluctuation range. By use of a temporary bench mark and the opo–survey, the non-geo-referenced water level was determined as 97.87 m. at Ngu'ra. One neter fluctuation range of 1964 to 2005 was therefore subtracted off this level for positioning ne indicative bottom level of the well for the wind pump. This if the trend remains onsistent, will form the lower possible fluctuation range for a minimum of two decades. This hould be adequate for the life time of the wind pump. Any other water source could also be nalyzed for sustainable pump installation.







ig: 5.2: **Kisumu Pier Lake Level Gauge Height Variation**

.2 Water Quality and Availability

summary report of the water quality analysis at Ng'ura is as in Table 5.5. The lake and ver water are good for irrigation when comparing their parameter characteristics in Table 5 to the standards as in Table A5.15 and A5.16 in the appendix. The only basic requirement this case, is filtration and tank sedimentation for use with drip irrigation as opposed to rect hose irrigation. The domestic water needs additional safe-handling for example boiling d other possible home treatment. The system envisaged that local methods of water ment would be instituted when used for the domestic purposes. Since better quality in case implies cheaper or simple procedure of managing the water, the lake intake (site) was preferable due to its relative superior water qualities compared with the river water site No. 1. The lake water quality variables showed indeed need to monitor the water onset and throughout the life time of the system. The established values should serve as m in view of possible changes (availability and quality) that may occur overtime of the ect operation. This is a factor that should be analyzed for any irrigation and especially irrigation.

water quality at Rusinga, however was good for irrigation because the shore line was y, deep with less influence from waves.

le:5.5: Lake Water Quality at and Next to Ng'ura Drip Irrigation Site

rameters	**H/Bay Sewerage Works**			**Bishop House**			**Site 2**	**River Mouth**		**Site 1**			**Ragwena Bridge**		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
ical															
perature.	25.3	24	24.6	25.4	23.4	24	24.7	23.8	24.1	25.2	23.8	24.5	24.4	24	24.7
(mg/l)	142	320	496	186	204	384	368	454	488	760	168	240	448	168	484
mical															
(mg/l)	94	73	82	73	74	75	12	76	75	1410	97	605	558	97	534
ductivity cm)	210	154	110	155	157	154	153	161	163	2910	205	1242	1154	205	624
ity (ppm)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.5	0.1	0.6	0.6	0.1	0.4
	8	7.8	8.5	7.9	9	8	7.5	7.5	8	8	7.5	7.5	8.5	7.5	8
l Alkalinity l)	101	68	80	51	52	72	84	98	78	886	82	684	504	82	310
lness (mg/l)	68	72	76	46	44	46	48	70	72	426	68	120	362	68	184
olved O_2 l)	6.8	5	6.6	6.5	6	6	6.8	5.8	6.8	3.2	2.2	2.4	2.8	2.2	2
ates (mg/l)	0.8	0.8	0.9	0.2	0.2	0.3	0:34	0.21	0.18		0.1	1.6	0.2	0.1	0.58
ophosphate l)	0.6	0.9	0.7	0.5	0.5	0.5	0.05	0.6	0.61	0.6	0.3	0.48	0.5	0.3	0.9
ride (mg/l)	5.8	6.5	5.2	3.8	5.4	4.1	5.4	5.6	4.8	12.5	5.2	5.8	11.4	5.2	4.8
(mg/l)	0.06	0.79	0.07	0.05	0.6	0	0.05	1.2	0.8	0.05	0.3	0.048	0.08	0.3	0.06
ogical															
oliforms 100ml)			200			123	120		130			105			100
oliforms 100ml)			92			102	84		110			66			106

A =7.10.2004 B = 29.10.2004 C = 1. 3. 2004

ere A, B and C are the respective sampling dates.

5.3.3 Estimating Reference Evapotranspiration at the Lake Shore

One parameter that has been of interest in irrigation for a long time is the ETo, especially within the lake Shore where there is problem of lack of developed standards and inadequate data. This hampers the use of the resource equations (equations 5.5 and 5.6) and the existing ormulae; Pan Evaporation, Pen Man equation, Radiation method and the temperature based Blanney – Criddle. Achievement of this may be alleviated through other approaches such as atellite data or specific software's developed to estimate data. It's from these estimates that he IR_g is arrived at by choosing the weather or soil formulae approach as is in Equations 5.3 and 5.2 respectively. The discharge (Q_s) from a wind pump should therefore balance with the parameters for the plant growth.

The satellite data are available for short durations and are inadequate. The reference evapotranspiration (ETo) was hence calculated using Penman Montieth formula with the available recorded data at five stations as in Table 5.6. In the Table there are also the low and high estimates based on the Loc Clime (Lce) estimator as designated by letters L and H. It is established that ETo calculated according to Penman and those according to LocClime oftware estimator are comparable for high values. These are shown in Table 5.6 and upported by Figures 5.2, 5.3 and B5.5 in the appendix. The accuracy depends on the database of the LocClime estimator. The LocClime estimator uses numerical methods to estimate values of the desired locations. This is done with adequate data base information for ocations around the site at which estimation is being undertaken. All the data used (Kibos, Ahero, Rusinga for example) for comparison were not factored within the data base except Kisumu. It did not have a way of including the data available from these other weather tations. If this were available, the method should have additional benefits and the ETo derived from LocClime software estimator will therefore be even better usable in estimating he Lake shore ETo.

ble:5.6: Penman Calculated and Compared to LocClim Estimated ET_0

Ng - CL/L	Ng - CL/H	K- Harg	K – Pen	K - Cl /H	Kad- Harg	Kad – Pen	Kad - CL/H	Kib- Harg	Kib -Pen	Kib - CL/H	Ah- Harg	Ah - Pen	Ah - Cl/H
3.8	4.4	3.6	5.1	5.4	3.2	4.7	5.4	4.4	5.4	5.4	4.5	5.4	5.5
3.7	4.3	3.6	5.3	5.3	3.4	4.8	5.2	4.2	5.3	5.3	4.4	5.5	5.4
4	4.4	3.5	5.4	5.2	2.9	4.8	5.1	4.1	5.4	5.2	4.1	5.5	5.3
3.4	3.9	2.5	4.7	4.8	2.2	4.2	4.8	3.2	4.7	4.8	3.1	4.9	4.9
3.4	3.7	2.5	4.4	4.2	2.3	4	4.3	3.1	4.4	4.3	3.3	4.6	4.4
3.2	3.7	2.8	4.2	4.4	2.6	3.9	4.4	3.2	4.1	4.5	3.5	4.5	4.6
3.4	3.8	2.7	4.1	4.1	2.5	3.9	4.1	3.3	4	4.1	3.3	4.2	4.3
3.5	4	2.8	4.5	4.5	2.7	4.1	4.5	3.3	4.4	4.4	3.7	4.5	4.6
3.6	4.3	3.3	4.8	5.4	2.8	4.5	5.5	3.6	4.8	5.4	4	5.1	5.6
3.8	4.5	3.5	5	5.3	2.8	4.5	5.4	4	5.2	5.3	4.1	5.3	5.4
3.3	4	3.2	5.3	5.2	2.6	4.3	5.2	3.8	5	5.2	3.9	5	5.3
3.4	4.1	3.3	5.4	5.5	3	4.4	5.5	4	4.5	5.5	4.2	5.1	5.7
3.5	**4.1**	**3.1**	**4.9**	**4.9**	**2.75**	**4.3**	**4.9**	**3.7**	**4.8**	**4.9**	**3.8**	**5**	**5.1**

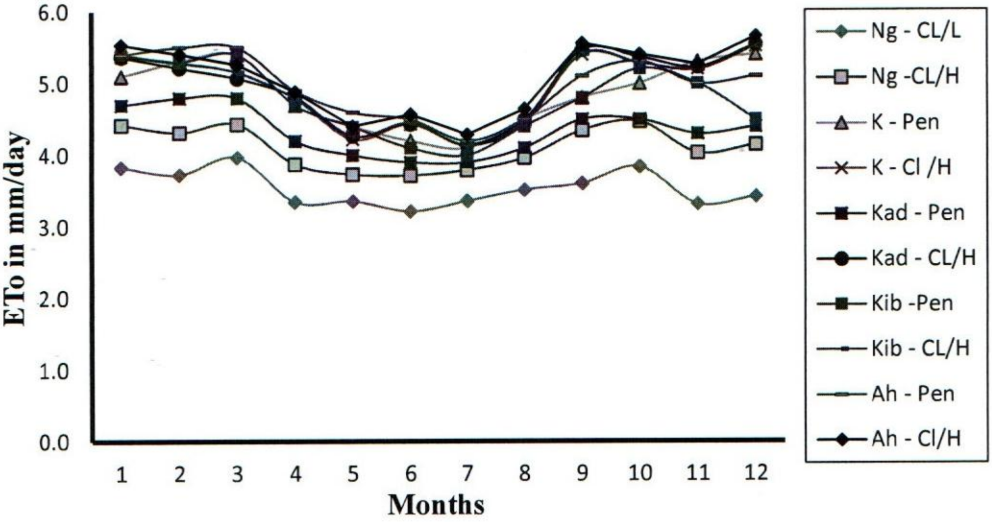
ere Ng is Ng'ura, K is Kisumu, Kad is Kadenge, Kib is Kibos, Ah is Ahero, LCl /LCh is Clime low and high and Pen is Penman calculated ETo.

ble:5.7: Ngura ETo Compared to Kisumu

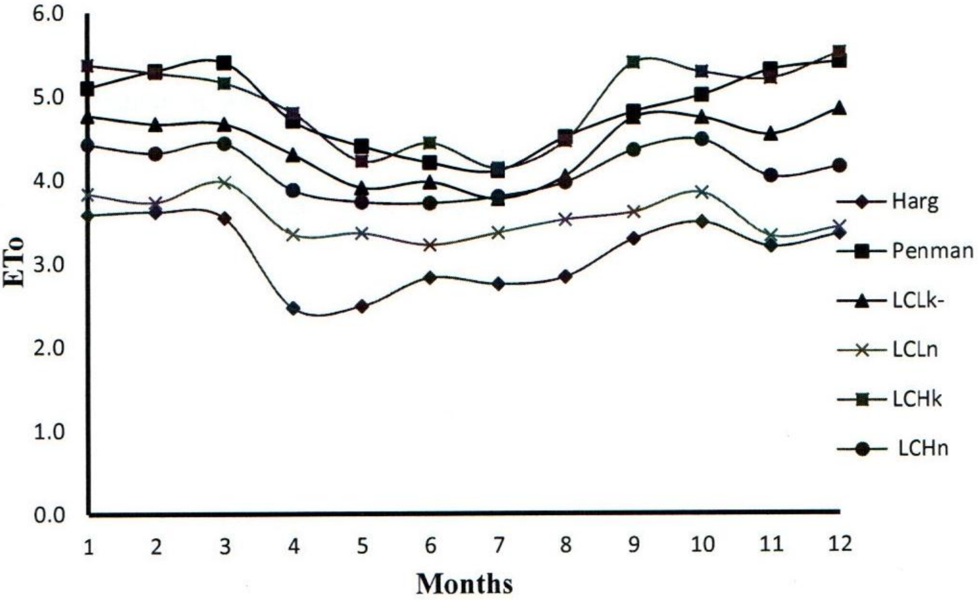
		ETo Kisumu and Ngura				
			Kisumu	**Ngu'ra**	**Kisumu**	**Ngu'ra**
	Harg	**Penman**	**LCLk-**	**LCLn**	**LCHk**	**LCHn**
	3.6	5.1	4.8	3.8	5.4	4.4
	3.6	5.3	4.7	3.7	5.3	4.3
	3.5	5.4	4.7	4	5.2	4.4
	2.5	4.7	4.3	3.4	4.8	3.9
	2.5	4.4	3.9	3.4	4.2	3.7
	2.8	4.2	4	3.2	4.4	3.7
	2.7	4.1	3.8	3.4	4.1	3.8
	2.8	4.5	4	3.5	4.5	4
	3.3	4.8	4.7	3.6	5.4	4.3
	3.5	5	4.7	3.8	5.3	4.5
	3.2	5.3	4.5	3.3	5.2	4
	3.3	5.4	4.8	3.4	5.5	4.1
a	**3.1**	**4.9**	**4.4**	**3.5**	**4.9**	**4.1**

ere: LC = Loc Clim Estimator; Harg = Hargreaves Equation

k = Kisumu; n =Ng'ura; H = high ETo estimate; L = Lower Eto estimate.



g: 5.3: Graphical Representation of Sites by Estimate Methods



ig: 5.4: ETo Estimate Methods Compared for Kisumu and Ng'ura

was found that Penman method gave ET$_0$ of 4.96 mm for Ahero, 4.85 mm for Kisumu, 4.8 m for Kibos, 4.3 mm for Kadenge, being the lowest. The New LocClim 1.10 however gave 4 mm for all the stations. The ETo based on Hargreaves gave 3.8 mm for Ahero, 3.1 for isumu, 2.8 for Kadenge and 3.7 for Kibos. Sample result for Ng'ura and Kisumu is as in gure 5.3 above while for the other stations are as in Fig 5.2. Figure 5.3 is specifically for isumu compared to Ng'ura.

Hargreaves output lagged behind both Penman and New LocClim 1.10 methods, but the patterns (Fig B5.5 in appendix) of the trend lines for the months of the year were similar.

As in Table 5.8 below, Hargreaves trend line (Kadenge) needs a factor of 1.59 and 0.98 to respectively be at the same level with New LocClim 1.10 and Penman, while LocClim 1.10 requires a factor 1.62 to be at the same level as Penman. In the neighbouring wetter climate of Kericho factors of 7.11 and 6.17 are required for Hargreaves to approximate Penmans and Lce (ETo). It can be stated that both Hargreaves and Lce with factors generated for the LS can be useful way within the LS for estimating ETo equivalent to Penman. The ratios generated for Kericho are higher for (Pen/Hargr, Lce/Harg) compared to Pen/Lce with reference to the other LS ratios (Table 5.8). Hence one can use Hargreaves where data is available and Lce where data is unavailable to estimate the Penman ETo estimates within the LS, also due to consistency observed in the trend lines.

It's observed that the LC suggests that the local climate within the LS is fairly similar with respect to Penman as was found with the estimates. This preliminarily can be attributed to the data base of New LocClim 1.10 which does not list or include data from the listed stations in Table 5.6. Kisumu/Kadenge and Kibos/Ahero as in Table 5.8 suggest their factors are comparable and respectively are close to the lake and inland. These suggest that ET$_o$ varies with distance from the lake.

Table:5.8: Ratios of Lake Shore ETo Estimate

Station	Pen/Hargr	Pen/Lce	Lce/Harg
Ahero	1.3	1.12	1.16
Kisumu	1.57	1.1	1.43
Kadenge	1.59	0.98	1.62
Kibos	1.3	1.08	1.2
Average	**1.44**	**1.07**	**1.35**
Kericho	7.11	1.16	6.17

.4 Estimating Wind Speeds at the Lake Shore

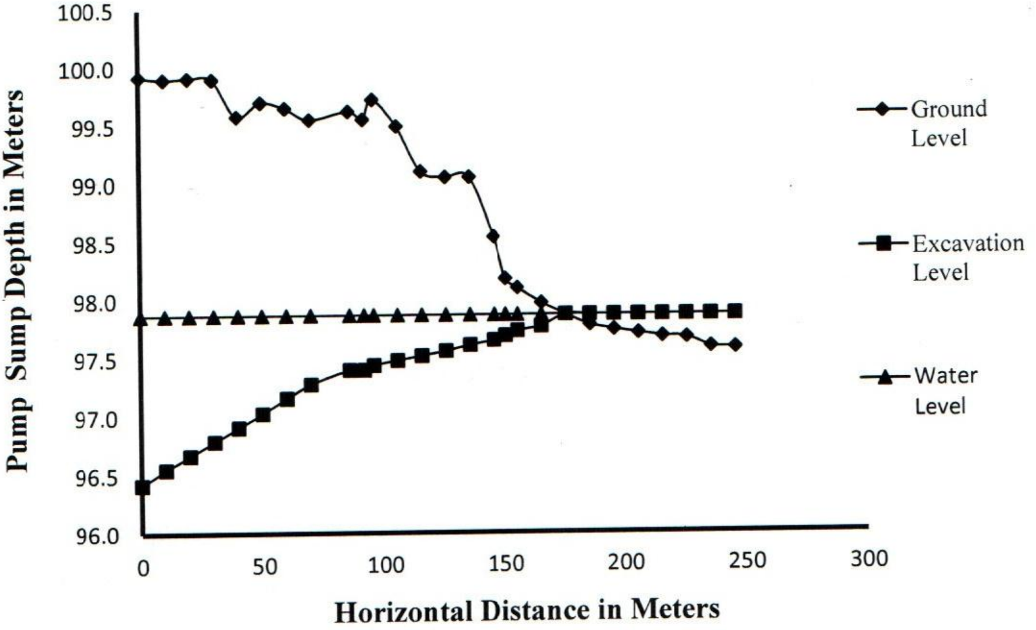
e measured and the Loc Clime generated wind speeds are as presented in Table 5.9. The nerated wind speeds are generally lower than the measured except in Kisumu where there agreement on the average values. This is not surprising for wind speeds because they pend on the locality. Kisumu's data is also part of the data base used for estimates for the rrounding area of the lake shore. The Table 5.9 thus indicates that an average factor of one required in order to arrive at the measured wind speeds for Kisumu. At Rusinga and uhuru the factor is respectively 2 and 1.8. Use of either of the factors brings the Loc Clime timated figures to compare closely to the measured data. Based on this, it is expected that nd speeds at Ng'ura should also have wind speeds that average 2.6 m/s to 2.9 m/s at the 2m ight of measurement. These average wind speeds strength when extrapolated to 10 m above ground level are adequate to drive a wind mill and are favourable for use with drip igation. These can further be compared to actual data measured as when measured at site.

ble:5.9: Ng'ura LocClim 2m Monthly Wind Run Estimate

g'ura Loc Clime Wind Estimates						
isumu	**K- Loc**	**Rusinga**	**R- Loc**	**Muhuru**	**M – Loc**	**Ng'ura Loc**
.57	1.7	2.87	1.6	2.53	1.7	1.1
.7	1.7	3.02	1.6	2.63	1.7	1.2
.72	1.8	2.98	1.3	2.71	1.8	1.2
.38	1.3	2.55	1.1	2.33	1.3	1.2
.12	1.2	2.23	1.2	2.25	1.2	1.6
.12	1.2	2.27	1.2	2.29	1.2	1.6
.27	1.2	2.4	1.3	2.47	1.2	1.6
.44	1.3	2.55	1.5	2.71	1.3	1.7
.46	1.5	2.6	1.7	2.84	1.5	1.7
.38	1.3	2.59	1.3	2.78	1.3	1.7
.38	1.3	2.54	1.2	2.55	1.3	1.5
.49	1.7	2.75	1	2.48	1.7	1.2
.4	**1.4**	**2.6**	**1.3**	**2.5**	**1.4**	**1.4**

3.5 Design and System Discharge

e intake site for Ng'ura and relation to the sump are depicted in Fig 5.4. The labeled rtical axis represents the depth of the wind pump sump. The water level is the horizontal e between the existing ground level and the dug level. The two coincide at approximately m where the ground level represents the lake bottom level into the lake. The inspection nber and sedimentation tank were added to give support in cleaning of water supply from ake at the intake side. It is on the sump that the wind pump was installed.



g: 5.5: **Wind Pump Sump Lake Level Relationship;**

design process/approach is a two-sided concept (Kabok and Chemelil, 2005) that must te system discharge and the crop water requirements (CWR) for the balancing of the ameters in equations 5.5 and 5.6. Headloss (H_s) for the system in Fig. B5.7 in appendix 2 .15m) included: P_e = 10m, topographical head (6m), system frictional head loss (1.6m), inline losses (7.7m) and 1.45m for the other losses due to additional equipment added to system (filter, water meter etc). Table 5.1 as a first guide to wind speed characteristics of area, showed that mean monthly wind speeds varied between 2.32 ms^{-1} in June to 3.1 ms^{-1} February. Deviations below the mean lower than 2 ms^{-1} were in the months of June and vember. It was observed that supplementary irrigation within the lakeshore would be most cessary between March to August, when water deficit exists. Monthly mean wind speed ge, considering yearly average and monthly standard deviations is observed to be between ms^{-1} (Table 5.1).

rom the wind speed range (2-3m/s), wind pump discharge size (Q_s) and using Table 5.2, the ystem discharge was determined by interpolation as $0.62m^3/hr$ for a total head of 22.15m ing between 20m and 40m total head. This however, could not be sustained by any of the ptions in Table 5.3. Test runs at site indicated that wind speeds were actually in the range of - 4m/s (Table 5.13 in section 5.5.6). Option III (Table 5.3) was therefore selected for the peration because the system discharge of wind pump was $1.7m^3/hr$ based on the water quirement.

he Pan Method results (Table 5.10) as opposed to Radiation, Blarney Criddle and Penman nodified) 1948, was selected for computation of water requirements. The ET_o values based n Epan were considered average compared to the other methods, thus used to avoid over rigation or under irrigation. Also that in the LS region, the equipment and data for the Pan ethod is more easily available. The maximum ET_o of 5.5 mm/day (Table 5.10) was etermined for the month of March with gross irrigation water requirement of 4.6 mm/day. he maximum irrigation interval based on soil and ET_{crop} parameters was thus calculated (12 ays), for the required emitter and system discharge. This meant that for maximum crop ater requirement in this case, irrigation was possible for 0.45 ha per season, on 12 hour day rigation, 5 days interval and system discharge of $1.7m^3/sec$.

able:5.10: Mean Daily Potential Evapotranspiration, Rusinga Data (1972 – 1981)

	MONTHS											
METHOD	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Blaney-Criddle	5.3	5	4.1	3.9	3.9	3.8	3.7	3.8	4	4.4	4.2	4.8
Pan Evaporation	5.2	5.3	5.5	4.4	4.1	4	4.3	4.6	5	5.2	4.6	4.9
Pen Man (1948) –Modified	6.4	6.6	6.2	5.5	5.1	5	5.2	5.5	5.9	6.2	5.8	6.1
Radiation	6.6	6.4	6.2	5.9	5.7	5.4	5.3	5.7	6	6.6	6.1	6.2

Table:5.11: Seasonal Water Requirement of Passion Fruit at Rusinga Island

	MONTH OF THE YEAR											
	Sep	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
ET_O Pan Evap. mm/day.	5	5.2	4.6	4.9	5.2	5.3	5.5	4.4	4.1	4	4.3	4.6
K_c	0.85	0.85	0.85	0.85	0.9	0.9	0.85	0.85	0.85	0.85	0.85	0.85
K_r	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.6	0.6	0.6	0.6	0.6
ET_{crop} mm/day	3.7	3.9	3.4	3.7	4.1	4.2	4.1	2.2	2.1	2.0	2.2	2.3
K_s	1	1	1	1	1	1	1	1	1	1	1	1
E_u	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
IR_g mm /day	4.1	4.3	3.8	4.1	4.6	4.7	4.6	2.4	2.3	2.2	2.4	2.6
IR_g L/day/Plant	36.9	38.7	34.2	36.9	41.4	42.3	41.4	21.6	20.7	19.8	21.6	23.4

NB: Irrigation interval = 5 days, hours per day of irrigation = 12, Area per plant = 1.8 m^2.

where E_a = irrigation efficiency, K_c = crop coefficient, E_u = design emission uniformity, K_r = takes care of non-beneficial evaporation which occur in the conventional irrigation methods, K_s = water storage efficiency, ET_o = potential evapotranspiration and ET_{crop} = crop evapotranspiration.

The same time period of the wind speed measurements was used for evaluation of the designed and installed wind pump drip irrigation system. Ordinarily, the established wind speed range from such data would be used to select a wind pump rotor diameter for a system to be established. In this case, the wind pump was installed hence the data together with the Kijito wind pump performance Table 5.2 was used for determining the possible discharge from the wind pump. The table is always obtained from the particular wind pump manufacturer.

5.3.6 Irrigation field Efficiency Tests

A total of 39 test runs were carried out three times daily in the month of November. The choice of time of test-runs captured the approximate difference in the wind speed pattern of the area. The pressure variations were taken care of by pressure compensating emitters used and the consistency nature of WS during the irrigation period LS.

Results of the average discharge of the test runs, the amount of water passing to the irrigation unit, pressure at the control head and the calculated emission uniformity (E_u%) are given in Table 5.12. Table 5.13 presents the calculated minimum discharge for the test runs, coefficient of variation (CV) of discharge of test runs, average wind speeds of the one hour measurement period that covered test run interval, and the absolute emission uniformity of the test runs calculated using equation (5.9). Sample result of a test run and calculations are given in Table 5.4 in section 5.4.1

The efficiencies given in Tables 5.12 and 5.13 are the result of equations 5.8 and 5.9. Average discharges in the respective tables were the result of sample test-runs, example given in Table 5.4. The sample test-run shows location of laterals on the manifold and the distribution points on the lateral.

The average of two adjacent discharge points denoted by letter A and B was taken as a single discharge point and resulted into sixteen discharge points within the micro-irrigation unit. The averages of the discharge points for each test-run time were then tabulated as in Table 5.4. The minimum discharge expressed as the average of the four lowest readings within the test-run unit was in turn tabulated as in Table 5.13. The average and minimum discharge of the two forms of efficiencies, for each day of the test-run irrespective of time of the day is further shown in Figures B5.8 and B5.10 in the appendix. Time system of emitter discharge and uniformity coefficients with regard to the time of the day are illustrated in Figure B5.10. in the appendix.

Table:5.12: Emission uniformity coefficient micro irrigation Test Runs – Rusinga Island

Date	Average Discharge ml/10 min/emitter			Average Discharge at Control Head m^3/10min			Pressure at Control Head (bar)			E$_U$%		
Time	10:00	12.30	3.20	10:00	12.30	3.2	10	12.3	3.2	10	12.3	3.2
3	496	570	533	0.34	-	-				90	91	95
4	528	536	549	0.32	0.21	0.34				94	94	93
5	551	577	535	0.22	0.34	0.47				93	93	95
6	493	531	538	0.31	0.21	0.31				94	95	96
9	570	534	560	0.23	0.47	0.43				95	90	93
10	557	533	561	0.23	0.33	0..39				91	95	91
11	534	553	550	0.23	0.34	0..33	> 0.8	> 1	> 1.2	91	95	97
12	538	534	552	0.33	0.43	0.25	> 0.8	>1	>1.8	94	94	92
							0.4 -					
13	531	535	562	0.43	0.33	0.24	0.6	1-1.6	>1.6>	94	94	94
								1.2 -				
14	509	519	530	0.31	0.43	0.31	>0.4	1.8	1-1.8	94	95	95
16	565	517	570	0.37	0.3	0.24	0.8-14	0.4	1.4-2	94	95	96
18	545	556	558	0.23	0..34	0.44	0.8-1.6	0.6	1-2.4	96	95	94
19	524	543	600	0.32	0.26	0.45	0.6	2-Jan	-	94	96	97
Aver.	534	541	553	0.3	0.33	0.35	-	-	-	93	94	94

Table:5.13: Absolute Emission Uniformity Coefficient, Micro-irrigation Test Runs - Rusinga Island

Date	Av. Min. discharge ml/10 min/emitter			Coefficient of variation (CV)			Test Run Average Wind Speed			E$_{UA}$		
Time	10	12	3.2	10	12.3	3.2	10	12.3	3.2	10	12.3	3.2
3	448	518	1015	8.1	6.6	4.3	3.2	4.1	9.4	90	91	95
4	495	502	513	5.1	5.1	5.8	3.2	2.2	3.2	93	93	93
5	511	549	506	5.8	3.7	5	4.2	3.9	3.6	93	95	93
6	465	502	516	4.2	4.2	4.1	2.8	2.8	3.9	94	95	95
9	543	479	521	3.8	8.1	4.9	4.5	3.9	6.2	94	91	94
10	505	527	511	6.4	3.9	7	4.5	3.5	-	91	95	92
11	487	486	533	6.4	5.7	3.1	2.4	5	-	91	92	96
12	504	504	509	5.3	4.6	6.1	2.6	3.9	3.1	93	93	91
13	497	502	530	6.1	4.3	4.3	1.7	3.8	4.1	92	94	94
14	479	493	505	4.3	4	4	2.1	3.5	4.6	94	94	94
16	533	491	547	4	4.6	4.2	3.7	3	3.6	94	94	94
18	521	526	525	4	4.6	4.5	2.4	2.9	4.3	95	95	94
19	492	522	579	4.9	3.1	3	1.9	3.6	2.9	94	96	97
Aver	498	508	523	5.3	4.8	4.6	3	3.5	4.4	93	94	94

ble 5.14 summarizes the analysis of variance for time of tests of 10.30a m, 12.30pm and 20pm. A one-way analysis of variance was used to check on the difference that could occur the average emitter discharges. The computed F-value and tabulated was 2.93 and 3.27 spectively. The probability (P-value) at 5% significance level was 0.661. This result shows at the difference in average discharge was not significant. This study therefore concludes at the discharge averages were constant at head control unit irrespective of pressure eveloped by the wind pump at different wind speeds. This confirms consistency in erformance of the system.

ubtracting minimum discharges in Table 5.13 from average discharges in Table 5.12 shows at the closer the difference to the total group standard deviation of 21 (Table 5.14), the gher was the percentage uniformity coefficient achieved. This is also exhibited in Figures 5.8 and B5.10 in the appendix. Any difference that was lower than two standard deviations owed uniformity coefficient lower than 93%. Increase or decrease in system discharge nnot be perfectly matched to the efficiency coefficients. This could be attributed to wind peed, the pressure compensating nature of the emitters and the water held in the pipe line hich could be pushed to the unit at minimal wind speed. Owing to the large interval of wind peed (1hr) measurements and the small test-run interval, this effect could not be explicit. It evident that the system efficiency did not follow wind speeds; it depended on the fference between the minimum and the average discharge with regard to the standard eviation. The coefficient of variation (Cv) was therefore also influenced by this henomenon.

able:5.14: Analysis of Variance of Mean Emitter Discharges

Time	**Mean**	**Sample Size**	**Group Std Deviation**		
10.30 am	533.92	13	24.336		
12.00 pm	546	13	19.425		
3.20 pm	553.69	13	18.741		
Total	544.54	39	20.983		
	Degrees of Freedom	**Sum of Squares**	**Mean Square**	**F**	P
Time	2	2582	1291	2.93	0.0661
Error	36	15849	440.27		
Total	38	18431.7			

$F_{0.05}$, 2, 36 = 2.93, Cases included = 39, missing cases = 0

Water supply at control head varied between 1.8m³/hr to 2.1m³/hr, this translated to 3.4%. This meant that an average of 1.8m³/hr minimum water was available from the wind pump. It upported the system design discharge choice of 1.7m³/hr (Table 5.2). A one-hour average wind speed was between 3.0m/s to 4.4 m/s, suggesting that 2- 3 m/s annual wind regime hosen earlier had to be revised to a regime of 3-4m/s. Pressure at the head control unit varied by up to 75% but was observed as non-significant (Table 5.12) for the emitter discharge. This was confirmed by the insignificant variations by the test runs average discharge and test run minimum discharge, which increased from 534 to 553 and 498 to 523 milliliters respectively. These varied with time (Fig B5.9 in appendix) and day of test Figures B5.8 and B5.10 in the appendix) but showed in Table 5.12, the efficiencies, the average remained constant at 93% in the morning and 94% in the afternoon. This is attributed o the temporal variations.

The average test run coefficient of variation (C_v) decreased from 5.3% to 4.6%, showing some improvement though small. This pointed out that increased average wind speeds in the morning meant improved average emitter discharges (Fig. B5.9 in the appendix) with time of the day, which corresponded with increased wind speed within the day. The variations of system discharges, efficiencies, and wind speed were consistent as shown in Figures B5.8 and B5.10 in the appedix and Tables 5.12 and 5.13. Wind regime therefore, as the prime mover was consistent. The design approach and approaches used can be upheld and replicated as the pressure and discharge variations were well regulated by the pressure compensating emitters. However, seasonality could affect results because of change of wind regime as was exhibited in the day variations.

Vermeiren and Jobling (1980) found values of E_u and E_{ua} determined in the field to range from 85% to 95%.respectively. Bralts (1981 a,b), on the other hand suggests that "the general criteria for $E_u$and E_{ua} values as; 90% or greater, excellent; 80 to 90%, good; 70 to 80%, fair; and less than 70%, poor". It can be deduced from the foregoing that the drip-irrigation unit performance was good based on trends above in spite of pressure variation due to wind speeds. The performance could also be attributed to the kind of emitter used (self-compensating) with an exponent value of nearly zero, screens at the head control unit, Arad water meter, and the water meter also reduced the emitter blockage.

onclusion and Recommendations

: Victoria Shore has potential for installation of wind pumps drip irrigation systems; ssible sites are affected by terrain characteristics and fetch distance surrounding the nps. Ng'ura was chosen as a case study site. In this case and others at Shore, hy and especially intake positioning is critically affected by the lake level ons. It is an important factor in laying of the water intake works, as it was observed y 10 years there was a change in depth of the lake, with a cumulative decrease of ich translated to 40m horizontal Lake recession from 1964 to 2004. It was also noted values increased inland from the lake water body and this could be attributed to the nts (aerodynamic and thermal) of evapotranspiration. It was therefore noted that the Lake the aerodynamic component are higher and lower inland while thermal e lower closer to the Lake and higher inland. Further that ETo calculated according in and those according to LocClime software estimator had two categories of high estimated values. It is only the high value category that was comparable to the calculated value. The quantity and quality of water at the Lake Shore was within use in irrigation but needs for filtration and constant monitoring of water quality for tions

ssion uniformity coefficient (E_u) and the absolute emission uniformity coefficient ained in this evaluation were higher than 90%. This confirmed that use of wind pump ssure compensating emitters performed acceptably well and gave equally comparable E_u and E_{ua}. Morning or afternoon wind speed variation resulted into a one percent e of 93% to 94%. This meant that the choice of wind pumps performance range; riteria and the efficiency of irrigation achieved were acceptable for use in a wind ip-irrigation system. Wind to discharge conversion efficiency however needs to be ed when appropriate equipments are available.

n with different wind pump rotor diameters however will need adjustment of n area because each rotor diameter performs differently in the same wind regime. The of non-pressure compensating emitters forms another important test area, rly to see the effect of wind speed variation with discharge along the laterals. Wind st runs or other method of test would also be of interest in this regard.

This study has demonstrated that a wind pump directly coupled to a drip-irrigation system is viable. The approach of synchronizing crop water requirement with WPDI system, wind pump discharge wind regime and the emitter discharge is considered a new development for the use of the two otherwise separate systems to enhance use of green energy

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APPENDIX A: TABLES

able:A5.15: Relative Clogging Potential of Water Used in Drip Irrigation Systems

Type of problem	Minor	Moderate	Severe
Physical			
Maximum suspended solids mg/l)	< 50	50–100	> 100
Chemical			
Ph	< 7.0	7.0–8.0	> 8.0
Maximum total dissolved solids (mg/l)	< 500	500–2,000	> 2,000
Conductivity (dS/m or mmhos/cm)	< 0.8	0.8-3.0	> 3.0
Maximum manganese concentration (mg/l)	< 0.1	0.1–1.5	> 1.5
Fe concentration (mg/l)	< 0.2	0.2–1.5	>1.5
H2S concentration (mg/l)	< 0.2	0.2–2.0	> 2.0
Biological			
Bacterial population (maximum number per ml)	< 10,000	10,000–50,000	> 50,000

Table:A 5.16: Water Quality Analysis

PARAMETER	VALUE	UNITS
Temperature	26.1	°C
Colour	-	Pt/co units
Dissolve oxygen	-	mg/l
Conductivity	720	µmho/cm
TDS	500	mg/l
TSS	-	mg/l
PH	7.46	
Turbidity	11.2	NTU
Total alkalinity	465	mg/l
Hardness	28	mg/l
Residual chlorides	-	
Chlorides	17.5	mg/l
Fluorides	2.85	mg/l
Manganese	0.02	mg/l
Magnesium	0.972	mg/l
Calcium	9.6	mg/l
Ammonia	0.106	mg/l
Nitrate	0.08	mg/l
Orthophosphate	-	mg/l
Total phosphorus	-	mg/l
Sulphate	17.8	mg/l
Silica	20.55	mg/l
Iron	0.07	mg/l
Nitrite	0.03	mg/l

***Sources*:** Modified from Hillel, 1982 and Hanson *et al*., 1994.

Notes: Electrical conductivity (EC) is a measure of the total dissolved salts (TDS). Approximately the relationship is: TDS (mg/l or ppm) = 640 x EC (dS/m or mmhos/cm).

APPENDIX B: FIGURES

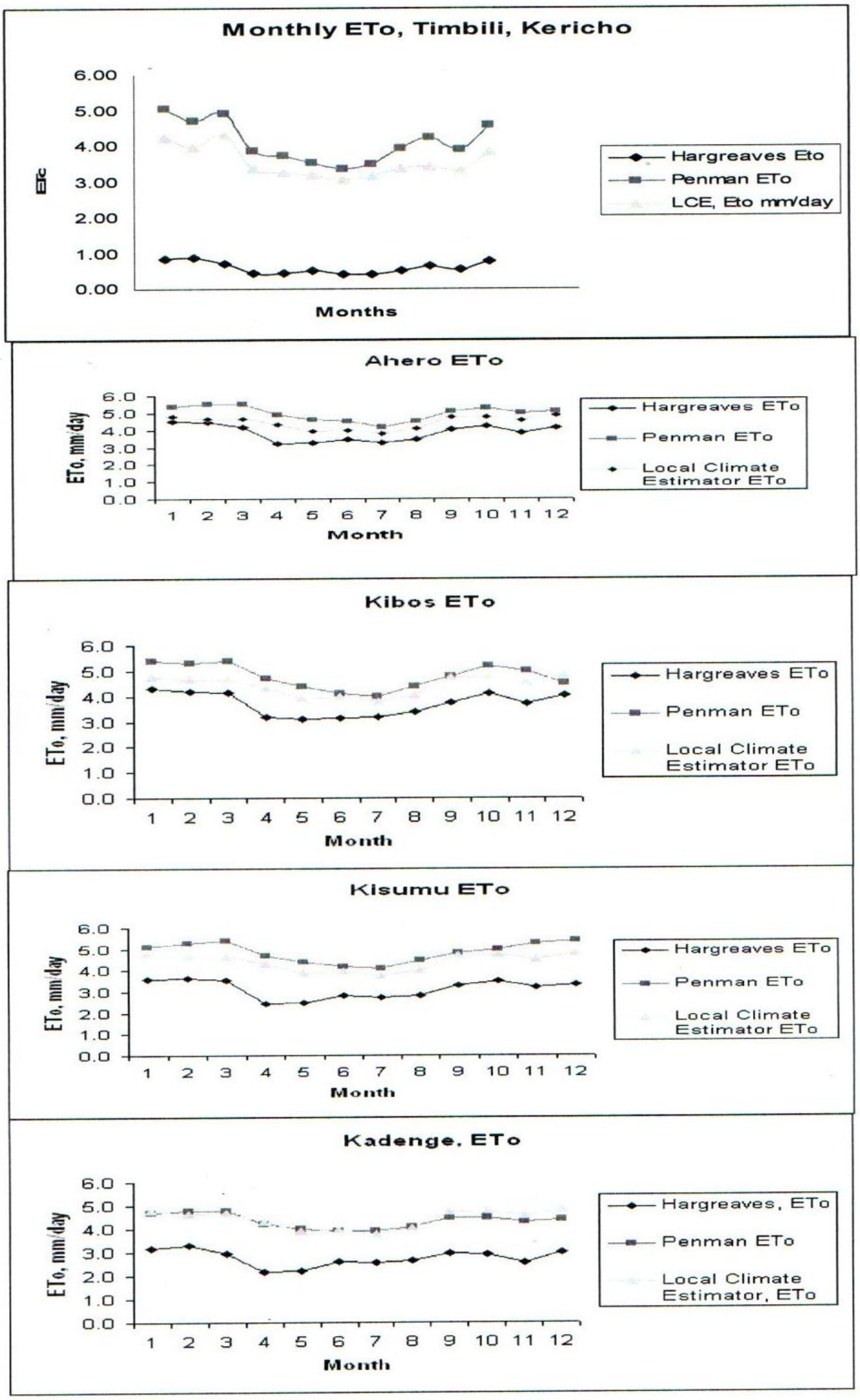
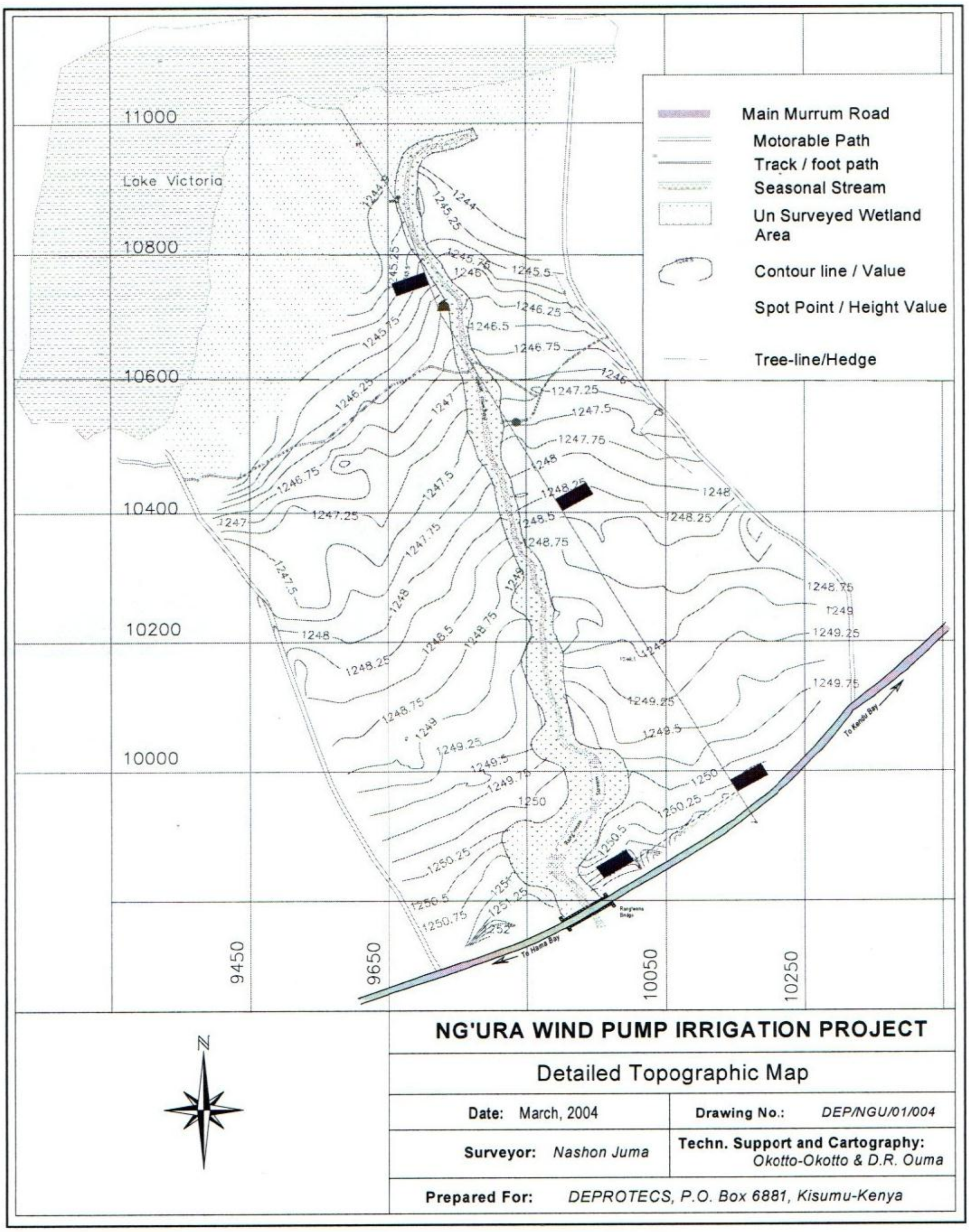


Fig: B5.6: Graphical Representation of Estimate Methods of other Lakeshore Stations



NG'URA WIND PUMP IRRIGATION PROJECT

Detailed Topographic Map

Date: March, 2004 | **Drawing No.:** *DEP/NGU/01/004*

Surveyor: *Nashon Juma* | **Techn. Support and Cartography:** *Okotto-Okotto & D.R. Ouma*

Prepared For: *DEPROTECS, P.O. Box 6881, Kisumu-Kenya*

Fig: B5.7: Topographic Map of Ng'ura Wind Pump Project

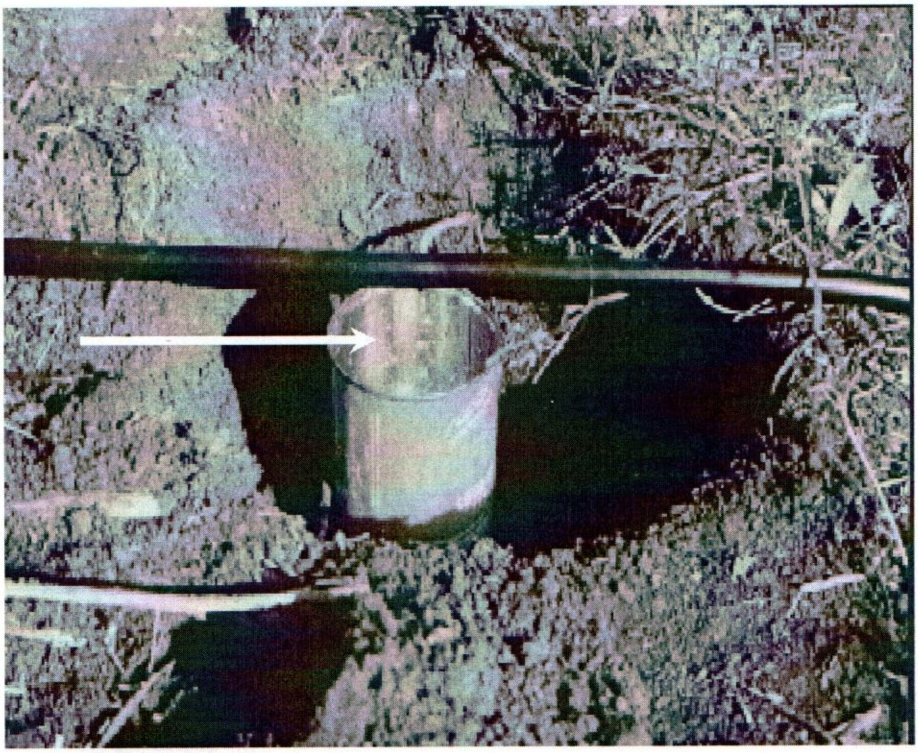
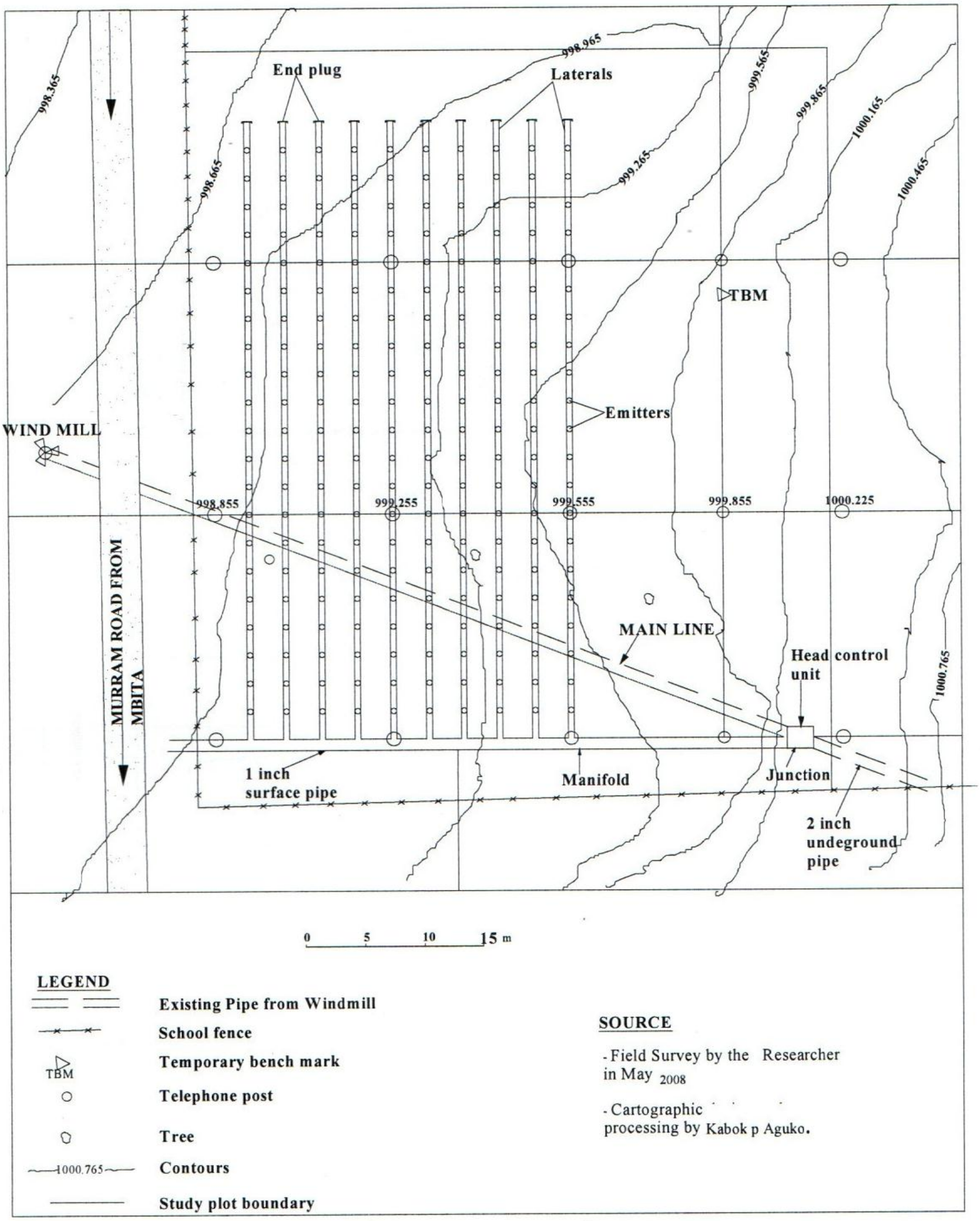


Plate 1: Water from Emitters



SOURCE

- Field Survey by the Researcher in May 2008

- Cartographic processing by Kabok p Aguko.

Fig: B5.8: Demonstration Plot for Drip-irrigation System at Tom Mboya Sec. School

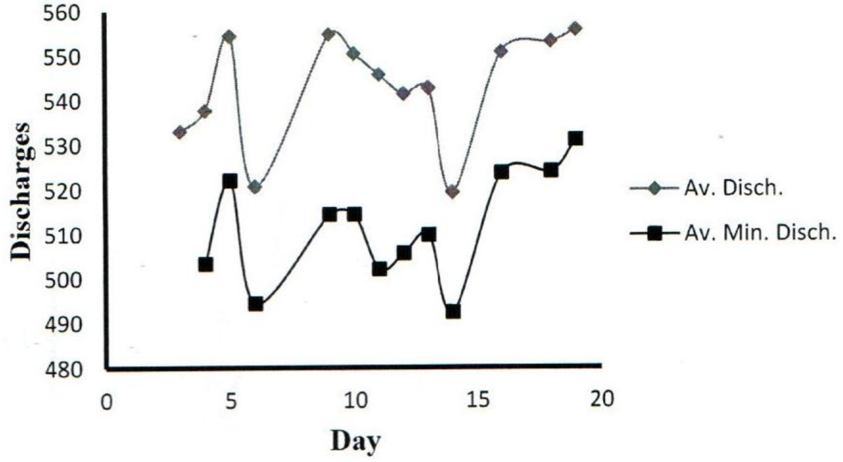


Fig: B 5.9: Day System (Average and Minimum) Emitter Discharges

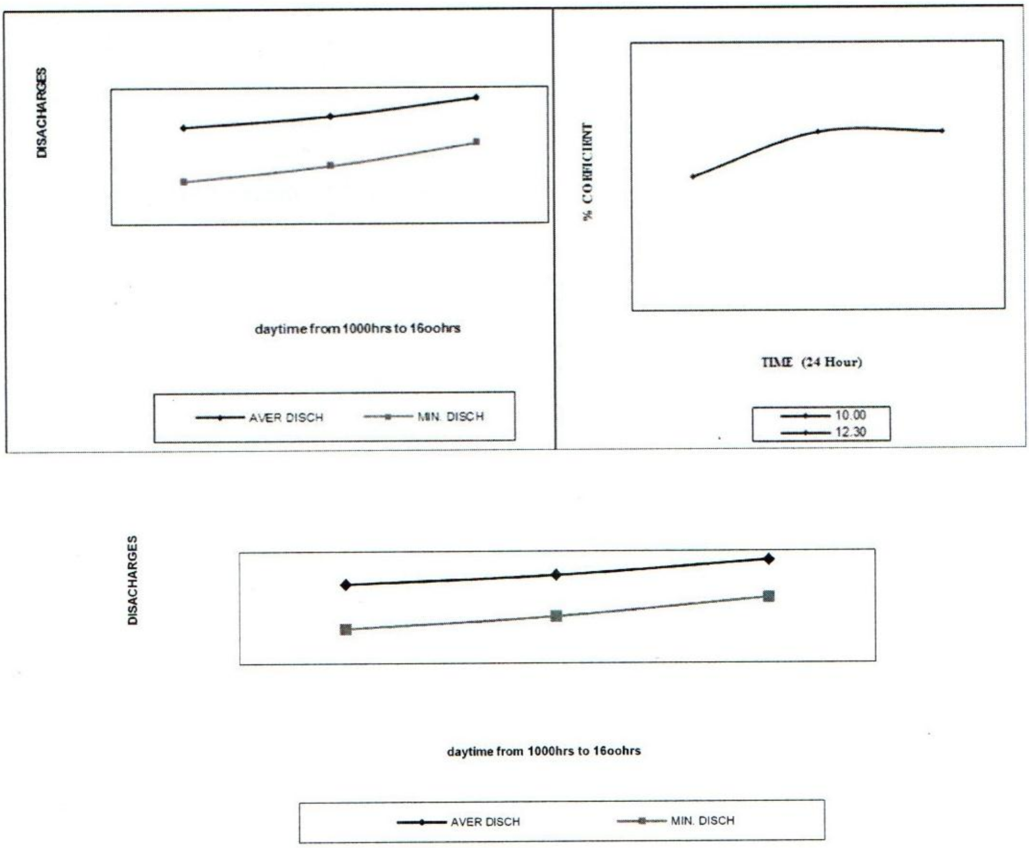


Fig: B5.10: (EU% and EUA) Uniformity Coefficients

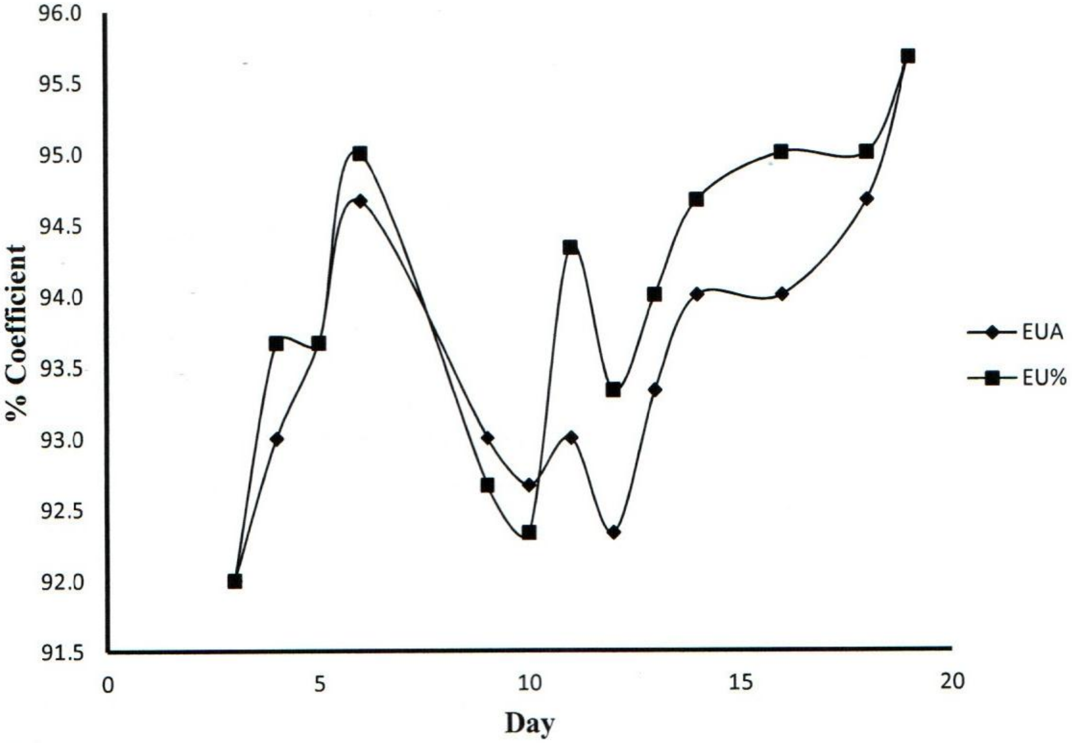


Fig: B5.11: Time System of Emitter Discharges and Uniformity Coefficients

CHAPTER SIX

GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Despite the difficulties experienced in data collection and even obtaining it, what is available gives a picture of the situation of wind speeds and other weather parameters within the Lake shore. The stations were representative and fair in distribution. Wind is noted as a variable resource within the Lake Shore area of Kenya by site, time, height and distance from the shore line. It was also established that the identified three categories of sites (Muhuru/Rusinga, Kisumu/Kadenge, Kibos/Ahero), wind speeds decreased as one moved inland. This is attributed to the higher roughness coefficient at the inland due to terrain, obstructions from human settlement and vegetation. The boundary layer also influences this behavior, attributed to minimal obstruction with increase height. Wind speeds also varied with time of day and seasons; were lower between 2000hrs to 0800hrs and increased thereafter. Also they were higher during the dry seasons compared to both moderate and rainy seasons. This is attributed to land and sea breezes caused by temperature difference. Notably all these variations were observed with comparable similarity.

It is possible to predict or estimate wind pump discharges by using the instantaneous discharge equations whose field performance may differ with type of wind pump and the wind speeds. The conceptual frame work and the chart for discharges developed can be used to determine irrigation depth and area for design, installation, operation and evaluation of the WPDI system.

The following identified precedent aspects and parameters to be considered for a WPDI system installation are: location and topography which was an output of a topo-survey, water (quantity and quality) was determined to adequate though needed filtration for the system, lake level fluctuation which varied vertically by 0.5m equivalent to 40 m distance surface variation and was used in the design of intake works, ET_O values varied between 3mm to 5mm daily. Soils (Kr) and Crop characteristics (Kc) were however estimated. The emission uniformity coefficient (E_u) and the absolute emission uniformity coefficient (E_{ua}) obtained in this evaluation were higher than 90%. This confirmed that use of wind pump with pressure compensating emitters performed acceptably well and gave equally comparable values of E_u and E_{ua}. Morning or afternoon wind speed variation resulted into a one percent difference of 93% to 94%. This meant that the choice of wind pumps performance range; design criteria and the efficiency of irrigation achieved were acceptable for use in a drip-irrigation system. Irrigation with different wind pumps rotor diameters; will need adjustment of irrigation area because each rotor diameter performs differently in the same wind regime.

This study has demonstrated that a wind pump directly coupled to a drip-irrigation system is feasible. The approach of synchronizing crop water requirement with respect to irrigation unit, wind pump output (discharge) based on its characteristics and wind regime and the emitter discharge is considered a new development for the use of the two otherwise separate systems.

6.2 Recommendations

The major challenge faced during this study was data inconsistency, poor and inadequate data capture equipment, and their sensitivity hence need for advanced methods such as GIS and satellite data capture.

Monitoring and evaluation of the WPDI system should be carried out to establish its, economic viability, impact and potential of up/out scaling to other wind potential areas. Controlled experiments should be done with other rotor diameters by use of wind tunnel tests for the discharge evaluation.

The behavior of non-pressure compensating emitters to test the effect of wind speed variation with discharge along the laterals.

Compare irrigation water application efficiency in relation to using other irrigation methods (sprinkler, furrow, basin, pressure and non-pressure and compensating pressure drips).